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AEDC-TR-67-228



# ALTITUDE DEVELOPMENTAL TESTING OF THE J-2 ROCKET ENGINE IN PROPULSION ENGINE TEST CELL (J-4) (TEST J4-1801-04)



N. S. Dougherty, Jr.

ARO, Inc.



January 1968

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LARGE ROCKET FACILITY
ARNOLD ENGINEERING DEVELOPMENT CENTER
AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE

# NOTICES

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1 Rocket motor - J-2

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## FOREWORD

The work reported herein was sponsored by the National Aeronautics and Space Administration (NASA), Marshall Space Flight Center (MSFC), under System 921E, Project 9194.

The results of the tests presented were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), Arnold Air Force Station, Tennessee, under Contract AF40(600)-1200. Program direction was provided by NASA/MSFC; engineering liaison was provided by North American Aviation, Inc., Rocketdyne Division, manufacturer of the J-2 rocket engine, and Douglas Aircraft Company, manufacturer of the S-IVB stage. The testing reported herein was conducted on August 3, 1967, in Propulsion Engine Test Cell (J-4) of the Large Rocket Facility (LRF) under ARO Project No. KA1801. The manuscript was submitted for publication on October 2, 1967.



This technical report has been reviewed and is approved.

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## ABSTRACT

Four firings of the Rocketdyne J-2 rocket engine were conducted in Test Cell J-4 of the Large Rocket Facility. A fifth firing attempt was aborted at t - 1 sec because the gas generator oxidizer supply line contained liquid-phase oxidizer. The firings were accomplished during test period J4-1801-04 at pressure altitudes ranging from 100,000 to 109,500 ft at engine start at predicted maximum starting energy S-V/S-IVB first burn conditions and maximum and minimum energy orbital restarting conditions. Satisfactory engine operation was obtained. The accumulated firing duration was 95.3 sec.

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## APPENDIXES

I. ILLUSTRATIONS

II. TABLES (Continued)



## NOMENCLATURE

| | |
|---|---|
| A | Area, in.$^2$ |
| ASI | Augmented spark igniter |
| ES | Engine start, designated as the time that helium control and ignition phase solenoids are energized |
| GG | Gas generator |
| MOV | Main oxidizer valve |
| Q | Volume flow, gal/sec |
| STDV | Start tank discharge valve |
| $t_0$ | Defined as the time at which the opening signal is applied to the start tank discharge valve solenoid |
| VSC | Vibration safety counts, defined as the time at which engine vibration was in excess of 150 g rms in a 960- to 6000-Hz frequency range |
| $\Delta P$ | Differential pressure, psi |

**SUBSCRIPTS**

| | |
|---|---|
| f | Force |
| m | Mass |
| t | Throat |

## SECTION I
## INTRODUCTION

Testing of the Rocketdyne J-2 Rocket Engine (S/N J-2052) using a Douglas Aircraft S-IVB battleship stage has been in progress since July 1966 at AEDC in support of the J-2 engine application on the Saturn IB and Saturn V launch vehicles for the NASA Apollo Program. Test J4-1801-04, reported herein, was conducted on August 3, 1967, and included four engine firings (04A, 04B, 04C, and 04E). A fifth firing attempt (04D) was aborted. The firings were accomplished at pressure altitudes ranging from 100,000 to 109,500 ft (geometric pressure altitude, Z, Ref. 1) at engine start in Propulsion Engine Test Cell (J-4) (Figs. 1 and 2, Appendix I) of the Large Rocket Facility (LRF) to investigate J-2 engine S-V/S-IVB start condition effects on (1) gas generator and augmented spark igniter chamber ignition characteristics and (2) fuel pump stall margin.

Based on the results of the previous test conducted on July 26, 1967, J4-1801-03 (Ref. 2), a lower thermal conditioning "red line" limit was imposed on the oxidizer supply line to the gas generator. This limit is defined as that condition permitting liquid oxidizer to fill the line beyond the liquid trap, which is designed to preclude the existence of liquid oxidizer in the gas generator at engine start.

## SECTION II
## APPARATUS

### 2.1 TEST ARTICLE

The test article was a J-2 rocket engine (Fig. 3) designed and developed by Rocketdyne Division of North American Aviation, Inc. The engine uses liquid oxygen and liquid hydrogen as propellants and has a thrust rating of 225,000 $lb_f$ at an oxidizer-to-fuel mixture ratio of 5.5. An S-IVB battleship stage was used to supply propellants to the engine. A schematic of the battleship stage is presented in Fig. 4.

Listings of major engine components and engine orifices for this test period are presented in Tables I and II, respectively (Appendix II).

All engine modifications and component replacements performed since the previous test period are presented in Tables III and IV, respectively. The thrust chamber heater blankets were in place during this test period, although they were not utilized.

### 2.1.1 J-2 Rocket Engine

The J-2 rocket engine (Figs. 3 and 5, Ref. 3) features the following major components:

1. Thrust Chamber - The tubular-walled, bell-shaped thrust chamber consists of an 18.6-in.-diam combustion chamber (8.0 in. long from the injector mounting to the throat inlet) with a characteristic length (L*) of 24.6 in., a 170.4-in.$^2$ throat area, and a divergent nozzle with an expansion ratio of 27.1. Thrust chamber length (from the injector flange to the nozzle exit) is 107 in. Cooling is accomplished by the circulation of engine fuel flow downward from the fuel manifold through 180 tubes and then upward through 360 tubes to the injector.

2. Thrust Chamber Injector - The injector is a concentric-orificed (concentric fuel orifices around the oxidizer post orifices), porous-faced injector. Fuel and oxidizer injector orifice areas are 25.0 and 16.0 in.$^2$, respectively. The porous material, forming the injector face, allows approximately 3.5 percent of total fuel flow to transpiration cool the face of the injector.

3. Augmented Spark Igniter - The augmented spark igniter unit is mounted on the thrust chamber injector and supplies the initial energy source to ignite propellants in the main combustion chamber. The augmented spark igniter chamber is an integral part of the thrust chamber injector. Fuel and oxidizer are ignited in the combustion area by two spark plugs.

4. Fuel Turbopump - The turbopump is composed of a two-stage turbine-stator assembly, an inducer, and a seven-stage axial-flow pump. The pump is self lubricated and nominally produces, at rated conditions, a head rise of 35,517 ft (1225 psia) of liquid hydrogen at a flow rate of 8414 gpm for a rotor speed of 26,702 rpm.

5. Oxidizer Turbopump - The turbopump is composed of a two-stage turbine-stator assembly and a single-stage centrifugal pump. The pump is self lubricated and nominally produces, at rated conditions, a head rise of 2117 ft (1081 psia) of liquid oxygen at a flow rate of 2907 gpm for a rotor speed of 8572 rpm.

6. Gas Generator - The gas generator consists of a combustion chamber containing two spark plugs, a pneumatically operated control valve containing oxidizer and fuel poppets, and an injector assembly. The oxidizer and fuel poppets provide a fuel lead to the gas generator combustion chamber. The high energy gases produced by the gas generator are directed to the fuel turbine and then to the oxidizer turbine (through the turbine crossover duct) before being exhausted into the thrust chamber at an area ratio ($A/A_t$) of approximately 11.

7. Propellant Utilization Valve - The motor-driven propellant utilization valve is mounted on the oxidizer turbopump and bypasses liquid oxygen from the discharge to the inlet side of the pump to vary engine mixture ratio.

8. Propellant Bleed Valves - The pneumatically operated fuel and oxidizer bleed valves provide pressure relief for the boiloff of propellants trapped between the battleship stage prevalves and main propellant valves at engine shutdown.

9. Integral Hydrogen Start Tank and Helium Tank - The integral tanks consist of a 7258-$in.^3$ sphere for hydrogen with a 1000-$in.^3$ sphere for helium located within it. Pressurized gaseous hydrogen in the start tank provides the initial energy source for spinning the propellant turbopumps during engine start. The helium tank provides a helium pressure supply to the engine pneumatic control system.

10. Oxidizer Turbine Bypass Valve - The pneumatically actuated oxidizer turbine bypass valve provides control of the fuel turbine exhaust gases directed to the oxidizer turbine in order to control the oxidizer-to-fuel turbine spinup relationship. The fuel turbine exhaust gases which bypass the oxidizer turbine are discharged into the thrust chamber.

11. Main Oxidizer Valve - The main oxidizer valve is a pneumatically actuated, two-stage, butterfly-type valve located in the oxidizer high pressure duct between the turbopump and the main injector. The first-stage actuator positions the main oxidizer valve at the 14-deg position to

obtain initial thrust chamber ignition; the second-stage actuator ramps the main oxidizer valve full open to accelerate the engine to main-stage operation.

12. Main Fuel Valve - The main fuel valve is a pneumatically actuated butterfly-type valve located in the fuel high pressure duct between the turbopump and the fuel manifold.

13. Pneumatic Control Package - The pneumatic control package controls all pneumatically operated engine valves and purges.

14. Electrical Control Assembly - The electrical control assembly provides the electrical logic required for proper sequencing of engine components during operation.

15. Primary and Auxiliary Flight Instrumentation Packages - The instrumentation packages contain sensors required to monitor critical engine parameters. The packages provide environmental control for the sensors.

### 2.1.2 S-IVB Battleship Stage

The S-IVB battleship stage is approximately 22 ft in diameter and 49 ft long and has a maximum propellant capacity of 46,000 lb of liquid hydrogen and 199,000 lb of liquid oxygen. The propellant tanks, fuel above oxidizer, are separated by a common bulkhead. Propellant prevalves, in the low pressure ducts (external to the tanks) interfacing the stage and the engine, retain propellant in the stage until being admitted into the engine to the main propellant valves and serve as emergency engine shutoff valves. Propellant recirculation pumps in both fuel and oxidizer tanks are utilized to circulate propellants through the low pressure ducts and turbopumps before engine start to stabilize hardware temperatures near normal operating levels and to prevent propellant temperature stratification. Vent and relief valve systems are provided for both propellant tanks.

Pressurization of the fuel and oxidizer tanks was accomplished by facility systems using hydrogen and helium, respectively, as the pressurizing gases. The engine-supplied gaseous hydrogen for fuel tank pressurization during S-IVB flight was routed to the facility venting system.

## 2.2 TEST CELL

Test Cell J-4, Fig. 2, is a vertically oriented test unit designed for static testing of liquid-propellant rocket engines and propulsion

systems at pressure altitudes of 100,000 ft. The basic cell construction provides a 1.5-million-$lb_f$-thrust capacity. The cell consists of four major components (1) test capsule, 48 ft in diameter and 82 ft in height, situated at grade level and containing the test article; (2) spray chamber, 100 ft in diameter and 250 ft in depth, located directly beneath the test capsule to provide exhaust gas cooling and dehumidification; (3) coolant water, steam, nitrogen (gaseous and liquid), hydrogen (gaseous and liquid), and liquid oxygen and gaseous helium storage and delivery systems for operation of the cell and test article; and (4) control building, containing test article controls, test cell controls, and data acquisition equipment. Exhaust machinery is connected with the spray chamber and maintains a minimum test cell pressure before and after the engine firing and exhausts the products of combustion from the engine firing. Before a firing, the facility steam ejector, in series with the exhaust machinery, provides a pressure altitude of 100,000 ft in the test capsule. A detailed description of the test cell is presented in Ref. 4.

The battleship stage and the J-2 engine were oriented vertically downward on the centerline of the diffuser-steam ejector assembly. This assembly consisted of a diffuser duct (20 ft in diameter by 150 ft in length), a centerbody steam ejector within the diffuser duct, a diffuser insert (13.5 ft in diameter by 30 ft in length) at the inlet to the diffuser duct, and a gaseous nitrogen annular ejector above the diffuser insert. The diffuser insert was provided for dynamic pressure recovery of the engine exhaust gases and to maintain engine ambient pressure altitude (attained by the steam ejector) during the engine firing. The annular ejector was provided to suppress steam recirculation into the test capsule during steam ejector shutdown. The test cell was also equipped with (1) a gaseous nitrogen purge system for continuously inerting the normal air in-leakage of the cell; (2) a gaseous nitrogen repressurization system for raising test cell pressure, after engine cutoff, to a level equal to spray chamber pressure and for rapid emergency inerting of the capsule; and (3) a spray chamber liquid nitrogen supply and distribution manifold for initially inerting the spray chamber and exhaust ducting and for increasing the molecular weight of the hydrogen-rich exhaust products.

An engine component conditioning system was provided for temperature conditioning engine components. The conditioning system utilized a liquid hydrogen-helium heat exchanger to provide cold helium gas for component conditioning. Engine components requiring temperature conditioning were the thrust chamber, crossover duct, pneumatic regulator, and main oxidizer valve closing control line and second-stage actuator. Helium was routed internally through the tubular-walled thrust chamber and crossover duct and externally

over the pneumatic regulator and main oxidizer valve closing control line and second-stage actuator.

## 2.3 INSTRUMENTATION

Instrumentation systems were provided to measure engine, stage, and facility parameters. The engine instrumentation was comprised of (1) flight instrumentation for the measurement of critical engine parameters and (2) facility instrumentation which was provided to verify the flight instrumentation and to measure additional engine parameters. The flight instrumentation was provided and calibrated by the engine manufacturer; facility instrumentation was initially calibrated and periodically recalibrated at AEDC. Appendix III contains a list of measured test parameters and the locations of selected sensing points.

Pressure measurements were made using strain-gage-type pressure transducers. Temperature measurements were made using resistance temperature transducers and thermocouples. Oxidizer and fuel turbopump shaft speeds were sensed by magnetic pickup. Fuel and oxidizer flow rates to the engine were measured by turbine-type flowmeters which are an integral part of the engine. The propellant recirculation flow rates were also monitored with turbine-type flowmeters. Engine side loads were measured with dual-bridge, strain-gage-type load cells which were laboratory calibrated before installation. Vibrations were measured by accelerometers mounted on the oxidizer injector dome and on the turbopumps. Primary engine and stage valves were instrumented with linear potentiometers and limit switches.

The data acquisition systems were calibrated by (1) precision electrical shunt resistance substitution for the pressure transducers, load cells, and resistance temperature transducer units, (2) voltage substitution for the thermocouples; (3) frequency substitution for shaft speeds and flowmeters; and (4) frequency-voltage substitution for accelerometers.

The types of data acquisition and recording systems used during this test period were (1) a multiple-input digital data acquisition system (MicroSADIC®) scanning each parameter at 40 samples per second and recording on magnetic tape, (2) single-input, continuous-recording FM systems recording on magnetic tape, (3) photographically recording galvanometer oscillographs, (4) direct-inking, null-balance potentiometer-type X-Y plotters and strip charts, and (5) optical data recorders. Applicable systems were calibrated before each test (atmospheric and altitude calibrations). Television cameras, in conjunction with video tape recorders, were used to provide visual coverage during an engine firing, as well as for replay capability for immediate examination of unexpected events.

## 2.4 CONTROLS

Control of the J-2 engine, battleship stage, and test cell systems during the terminal countdown was provided from the test cell control room. A facility control logic network was provided to interconnect the engine control system, major stage systems, the engine safety cutoff system, the observer cutoff circuits, and the countdown sequencer. A schematic of the engine start control logic is presented in Fig. 6. The sequence of engine events for a normal start and shutdown is presented in Figs. 7a and b. The facility control logic network has the provisions for sequencing the stage prevalves open and recirculation systems off for engine start, as they were during the flight of the vehicle AS-501 S-IVB stage. The normal logic more closely duplicated the start sequence for S-IVB orbital restart; the auxiliary logic mode closely duplicated the start sequence for S-IVB first burn. The two control logics are presented in Figs. 7c and d.

# SECTION III
# PROCEDURE

Preoperational procedures were begun several hours before the test period. All consumable storage systems were replenished, and engine inspections, leak checks, and drying procedures were conducted. Propellant tank pressurants and engine pneumatic and purge gas samples were taken to ensure that specification requirements were met. Chemical analysis of propellants was provided by the propellant suppliers. Facility sequence, engine sequence, and engine abort checks were conducted within a 24-hr time period before an engine firing to verify the proper sequence of events. Facility and engine sequence checks consisted of verifying the timing of valves and events to be within specified limits; the abort checks consisted of electrically simulating engine malfunctions to verify the occurrence of an automatic engine cutoff signal. A final engine sequence check was conducted immediately preceding the test period.

Oxidizer dome, gas generator oxidizer injector, and thrust chamber jacket purges were initiated before evacuating the test cell. After completion of instrumentation calibrations at atmospheric conditions, the test cell was evacuated to approximately 0.5 psia with the exhaust machinery, and instrumentation calibrations at altitude conditions were conducted. Immediately before loading propellants on board the vehicle, the cell and exhaust-ducting atmosphere was inerted. At this same time, the cell nitrogen purge was initiated for the duration of the test period, except for the engine firing. The vehicle propellant tanks were

then loaded, and the remainder of the terminal countdown was conducted.

Temperature conditioning of the various engine components was accomplished as required, using the facility-supplied engine component conditioning system. Engine components which required temperature conditioning were the thrust chamber, the crossover duct, pneumatic regulator, main oxidizer valve closing control line, and main oxidizer valve second-stage actuator. Table V presents the engine purges and thermal conditioning operations during the terminal countdown and immediately following the engine firing. The engine component conditioning system utilized a liquid hydrogen-helium heat exchanger to provide the chilled helium for component conditioning.

An external purge conditioning system for the gas generator oxidizer supply line was provided on engine J-2052 (refer to Rocketdyne Field Directive RFD-32-67). It consisted of a shroud formed by two pliable tubes of 0.016-in.-thick, clear Teflon®, 2.5 in. in diameter, 17 in. long, jointed by an aluminum sleeve. The shroud extended from the oxidizer bleed valve to the gas generator oxidizer inlet. Ambient temperature gaseous nitrogen was supplied to the shroud. A double layer of asbestos insulation and an electric heater, set to control at -50 ± 10°F and to provide 300 watts of heat addition, were installed on the shroud before the subject test.

The conditioning shroud was designed to provide simulation of ground test environmental (not flight) conditions for the oxidizer line by maintaining approximately 15-psia nitrogen pressure locally over the entire length of the line.

## SECTION IV
## RESULTS AND DISCUSSION

### 4.1 SUMMARY

During the four firings conducted on August 3, 1967 (test J4-1801-04), a total of 95.3 sec of engine operating time was accumulated. The firings were conducted in the following sequence and for nominal durations of:

| | |
|---|---|
| 04A | 30 sec |
| 04C | 30 sec |
| 04B | 5 sec |
| 04E | 30 sec |

A fifth firing attempt (04D) followed firing 04E but was aborted at t -1 sec countdown time.

All of the firings were in support of the J-2 engine developmental program for the S-V/S-IVB launch vehicle. The simulated pressure altitudes at engine start varied from 100,000 to 109,500 ft. Thermal conditioning of the thrust chamber and selected engine components (crossover duct, main oxidizer valve, second-stage actuator cap and closing control line, and pneumatic control package) was accomplished to simulate the J-2 engine thermal conditions predicted for flight. The gas generator oxidizer supply line was thermal conditioned to -50 ± 10°F for firings 04A, 04B, and 04C. Firing 04E and firing attempt 04D repeated the conditions of firings 04A and 04B, respectively, with the exception that the gas generator oxidizer supply line was not conditioned. Table VI presents the conditioning targets for the engine components and the measured test conditions at engine start. The pump inlets, start tank, and helium tank pressure and temperature conditions at engine start are shown in Fig. 8.

Propellant utilization valve excursions to the closed position (changing engine mixture ratio to 5.5) were made during firings 04A, 04C, and 04E to obtain maximum turbine hardware heating during 30 sec of engine operation for simulation of 80-min orbital coast and engine restart at the predicted crossover duct temperature level.

Specific test objectives and a brief summary of results of the firings are as follows:

| Firing | Test Objective | Results |
|---|---|---|
| 04A | Evaluate the effects of S-V/S-IVB first burn thrust chamber resistance on gas generator outlet temperature and evaluate augmented spark igniter operation at maximum starting energy. | No indications of excessive augmented spark igniter chamber temperature. Thrust chamber resistance effect could not be evaluated because necessary gas generator oxidizer supply line thermal conditioning limits were not met. |

| Firing | Test Objective | Results |
|---|---|---|
| 04C | Evaluate the effects of minimum starting energy for S-V/S-IVB restart on fuel pump high level stall margin and thrust chamber pressure buildup time. | Test objectives were met. Fuel pump stall margin was 600 gpm. Buildup time to 550-psia chamber pressure was 2.758 sec. |
| 04B | Evaluate the effects of minimum model specification fuel pump inlet pressure and maximum S-V/S-IVB first orbit restarting energy on engine start transient and fuel pump low level stall margin. | Test objectives were met Conservative (over 1300-gpm) fuel pump stall margin was maintained in the low level region. |
| 04E | Repeat of firing 04A with all test conditions the same except that the gas generator oxidizer supply line was not conditioned. | All objectives were met. Thrust chamber resistance effect showed roughly a 1:1 increase in gas generator peak temperature for decreased thrust chamber temperature. No indications of excessive augmented spark igniter temperatures. |
| 04D | Repeat of firing 04B with all test conditions the same except that the gas generator oxidizer supply line was not conditioned. | Test was aborted at t - 1 sec countdown time because gas generator oxidizer supply line thermocouples indicated presence of liquid oxidizer beyond the liquid trap. |

The presentation of test results in the following sections will consist of a discussion of each firing with pertinent test comparisons essential to the above evaluations. The data presented will be that recorded on the digital data acquisition system, except as noted.

## 4.2 TEST RESULTS

### 4.2.1 Firing J4-1801-04A

The programmed 30-sec engine firing was successfully accomplished. Test conditions at engine start are presented in Table VI. The programmed fuel lead time was 3 sec. Engine start and shutdown transients

are shown in Fig. 9. Table VII presents selected engine valve operating times for start and shutdown. The test cell (engine ambient) pressure altitude at engine start was 100,000 ft. Figure 10 presents engine ambient pressure and thrust chamber pressure for the firing duration. Combustion chamber pressure reflects the propellant utilization valve excursion at about $t_0$ + 10 sec, which changed the engine mixture ratio from 5.0 to 5.5.

Thermal conditioning history of selected engine components is shown in Fig. 11. The temperature profile of the gas generator oxidizer supply line at engine start is shown in Table VIII. Evaluation of the thrust chamber resistance effect on gas generator outlet peak temperature for maximum S-V/S-IVB starting energy was to be accomplished by duplicating all of the firing 02A conditions (Ref. 5), except for prechilling the thrust chamber 100°F colder. Table IX shows that all of these starting conditions of firings 02A and 04A were similar, except for the warmer gas generator oxidizer supply line temperature profile on firing 04A. Reference 6 states that a colder thrust chamber (reduced thrust chamber resistance to fuel flow) will produce a higher gas generator peak temperature, all other conditions being equal. The peak temperatures on firings 04A and 02A were approximately the same. The expected thrust chamber resistance effect between firings 04A and 02A was apparently negated by the unexpected gas generator oxidizer supply line temperature effect (to which the slight reduction in peak temperature was attributed).

There was no evidence from post-firing physical examination that excessive augmented spark igniter chamber temperatures had occurred. Thus, augmented spark igniter operation was deemed to have been completely satisfactory during this test. Ignition was detected in the igniter chamber 0.215 sec after engine start.

Thrust chamber ignition (defined as the time when thrust chamber pressure reaches 100 psia) occurred at $t_0$ + 1.003 sec. Vibration safety cutoff counts were recorded for 97 msec, beginning at $t_0$ + 0.984 sec. The main oxidizer valve second-stage initial movement occurred at $t_0$ + 0.985 sec. Thrust chamber pressure buildup time to 550 psia was 1.902 sec.[1] All valve operating times were consistent and normal.

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[1]The 550-psia level was chosen to allow comparison of all firings, either open or null propellant utilization valve position, in buildup time to a distinct level above the "main-stage" pressure switch level.

Although the closing of the gas generator control valve appeared normal, an abnormally high gas generator shutdown transient temperature was recorded (Fig. 9).

The 1860°F gas generator temperature, approximately 4 sec after engine cutoff, indicated possible leakage of oxidizer from the gas generator oxidizer poppet. A leak check conducted approximately 1 hr subsequent to firing 04A, by pressurizing the oxidizer system to 35 psia and operating the recirculation pump for 5 min, revealed that only slight leakage was present.

#### 4.2.2 Firing J4-1801-04C

The programmed 30-sec engine firing was successfully accomplished. Test conditions at engine start are presented in Table VI. The programmed fuel lead time was 8 sec. Engine start and shutdown transients are shown in Fig. 12. Valve operating times, shown in Table VII, were consistent and normal. The engine ambient pressure altitude at engine start was 108,000 ft. Figure 13 presents engine ambient pressure and thrust chamber pressure for the firing duration. Combustion chamber pressure reflects the propellant utilization valve excursion from the open to the closed position at about $t_0$ + 11.5 sec, which changed the engine mixture ratio from 4.4 to 5.5.

Thermal conditioning history of selected engine components is shown in Fig. 14. Engine start conditions were set for minimum restarting energy within the specified tolerances. Thrust chamber ignition occurred at $t_0$ + 1.100 sec. Vibration safety cutoff counts occurred for 4 msec at $t_0$ + 0.544 sec and for 15 msec at $t_0$ + 1.083 sec. Thurst chamber pressure buildup time to 550 psia was 2.758 sec, the longest buildup time recorded to date in the AEDC test program. The main oxidizer valve began the second-stage ramp at $t_0$ + 1.028 sec. Ignition was detected in the augmented spark igniter chamber 0.332 sec after engine start. All valve operating times were consistent and normal.

Transient fuel pump head/flow data, compared to the stall inception line for the fuel pump, are presented in Fig. 15. The minimum stall margin was approximately 600 gpm, occurring at approximately 19,000 rpm. The fuel pump was rotating at approximately 970 rpm before the start tank discharged (see Fig. 12). This is indicative of the unusually high flow rate of fuel that was attained during the 8-sec fuel lead period by prechilling the thrust chamber to -120°F before

engine start. Figure 15 shows the conservative fuel pump stall margin (approximately 2000 gpm) afforded by the thrust chamber prechill which preceded this firing.

#### 4.2.3 Firing J4-1801-04B

The programmed 5-sec engine firing was accomplished 19 min after firing J4-1801-04C. The crossover duct cooldown rate to the level predicted for 80-min orbital restart is shown in Fig. 16. The propellant utilization valve was in the open position throughout the firing.

Engine start and shutdown transients are shown in Fig. 17. The programmed fuel lead time was 8 sec. All valve operating times, shown in Table VII, were consistent and normal. The engine ambient pressure altitude at engine start was 109,500 ft. Figure 18 presents engine ambient pressure and thrust chamber pressure for the duration of the firing. Test conditions at engine start are shown in Table VI. Thermal conditioning history of selected engine components is shown in Fig. 19. The temperature profile of the gas generator oxidizer supply line was similar to that attained on firing 04A (Table VIII). Conservative low level fuel pump stall margin (over 1300-gpm) was maintained, as shown in Fig. 20, with a fuel pump inlet pressure at engine start of 27.6 psia (see Fig. 8a).

Thrust chamber ignition occurred at $t_0$ + 0.948 sec, without the occurrence of excessive vibration. The main oxidizer valve began the second-stage ramp at $t_0$ + 1.098 sec. Thrust chamber pressure buildup time to 550 psia was 1.915 sec. Ignition was detected in the augmented spark igniter chamber 0.259 sec after engine start.

#### 4.2.4 Firing J4-1801-04E

The programmed 30-sec engine firing was successfully accomplished. Test conditions at engine start are presented in Table VI. The programmed fuel lead time was 3 sec. Engine start and shutdown transients are shown in Fig. 21. Valve operating times, shown in Table VII, were consistent and normal. The engine ambient pressure altitude at engine start was 107,000 ft. Figure 22 presents engine ambient and thrust chamber pressure for the firing duration. Combustion chamber pressure reflects the propellant utilization valve excursion from the null position to the closed position at about $t_0$ + 10 sec, which changed the engine mixture ratio from 5.0 to 5.5.

Thermal conditioning history of selected engine components is shown in Fig. 23. The temperature profile of the gas generator oxidizer supply line at engine start is shown in Table VIII. Table IX shows that all of the firing 04E starting conditions (except thrust chamber temperature) were in close agreement with those attained on firing 02A, permitting isolation of the desired single variable, thrust chamber temperature. The gas generator peak temperature attained during the firing 04E start transient was 2200°F.

Augmented spark igniter operation was deemed satisfactory during this firing, based on no evidence, during post-firing physical examination, of igniter chamber erosion. Ignition was detected in the igniter chamber 0.225 sec after engine start.

Thrust chamber ignition occurred at $t_0$ + 0.976 sec. Vibration safety cutoff counts were recorded for 33 msec, beginning at $t_0$ + 0.976 sec. The main oxidizer valve second-stage initial movement occurred at $t_0$ + 0.985 sec. Thrust chamber pressure buildup time to 550 psia was 1.885 sec.

#### 4.2.5 Firing Attempt J4-1801-04D

The programmed 5-sec engine firing was aborted at 1 sec before the fire command signal because the gas generator oxidizer supply line temperature profile indicated the presence of liquid oxidizer to thermocouple TOBS-2A (Table VIII). An indication of liquid oxidizer at the top of the liquid trap meant that it was possible for liquid to have extended beyond the trap toward the gas generator. Firing 03B (Ref. 2) had resulted in a gas generator overtemperature problem with the same gas generator oxidizer supply line conditions that existed before firing 04D. For this reason, firing 04D was aborted.

The history of the gas generator oxidizer supply line temperature profile following firing 04E, during the 19-min coast period required for crossover duct cooldown to the predicted 80-min restart level, is shown in Fig. 24. This restart was planned with 10 min of propellants-in-engine time. Figure 24 shows the warming trend after oxidizer was expelled following firing 04E. The supply line began to chill down again when the propellant prevalves were opened for the firing 04D restart. The "red line" limit was reached when the oxidizer ullage pressure was increased to the required starting level (48-psia). The warming trend shown during the 115-sec hold at fire command - 1 sec resulted from a last-minute effort to warm the line using the conditioning shroud heater.

## 4.3 GAS GENERATOR OXIDIZER SUPPLY LINE CONDITIONING

The gas generator oxidizer supply line conditioning system was originally installed on the engine before test J4-1554-26 (conducted April 4, 1967, Ref. 6).

The integrity of the conditioning shroud had significantly degraded before the subject test was conducted. The shroud developed a number of perforations, caused by cracking, and could not be adequately pressurized. The shroud was insulated, and the heater was added, before the subject test, to protect the oxidizer line from being inadvertently chilled by cold helium gas used for conditioning other components in close proximity. The required -50 ± 10°F environment for firings 04A, 04B, and 04C (refer to Tables VI and VIII) was satisfactorily attained by operating the oxidizer line conditioning system at an increased nitrogen purge supply pressure which yielded a flow rate through the shroud estimated at about 80 scfm. Conditioning, therefore, was accomplished by forced-convection heat addition. For firing 04E and firing attempt 04D, the purge and the heater were turned off (removing the sources of heat addition). Thus, the configuration for these firings was a well-insulated gas generator oxidizer supply line with near vacuum between the oxidizer line and the insulation.

The effect of the differences in conditioning procedure is apparent in the comparisons shown in Table IX. Both firings 04A and 04E repeated the test conditions of firing 03A with the same objective of isolating thrust chamber resistance as the test variable when compared with firing 02A. The gas generator oxidizer supply line configuration for firings 03A and 03B was as shown in Fig. 25 (with the uninsulated shroud), and the nitrogen purge was not utilized. The oxidizer line was exposed to component chill gases used for providing predicted thermal conditions on other components in close proximity. Gas generator oxidizer supply line conditioning was the significant variable between firings 03A, 04A, and 04E. Firing 03A shows a 450°F higher gas generator peak temperature than firing 04A for liquid oxidizer throughout the line at engine start on firing 03A and gaseous oxidizer throughout the line on firing 04A. Firings 04A and 04E show only a 160°F gas generator peak temperature difference (with liquid oxidizer contained in the liquid trap on firing 04E).

Gas generator oxidizer supply line conditioning was the only significant variable between firings 03B and 04B, producing a 500°F gas generator peak temperature increase on firing 03B. Liquid oxidizer extended throughout the oxidizer line at engine start on firing 03B. The line contained only gaseous oxidizer on firing 04B.

## 4.4 THRUST CHAMBER RESISTANCE EFFECT

Thrust chamber resistance to fuel flow is a variable primarily dependent upon thrust chamber prechill temperature and is defined, for the purposes of this report, as:

$$\frac{\text{Fuel Pump Discharge Pressure-Thrust Chamber Pressure}}{(\text{Fuel Volumetric Flow Rate})^2}$$

Figure 26 shows the resistance values during the fuel lead and gas generator ignition transients for firing 04E compared with firing 02A. These two tests represent the extreme limits in thrust chamber temperature expected at engine start for S-V/S-IVB first burn.

A comparison of the gas generator start transients for firings 04E and 02A is presented in Fig. 27. Figure 27a shows that gas generator oxidizer injector pressures were nearly equal for both tests and that gas generator fuel injector and chamber pressures were slightly higher on firing 02A. Figures 27b and c show the gas generator ignition transient details as the gas generator control valve opened. Gas generator ignition was detected at $t_0$ + 0.642 sec on firing 02A and 20 msec later, at $t_0$ + 0.662 sec on firing 04E. The oxidizer poppet had been open for 25 msec longer before ignition occurred on firing 04E.

The effect of thrust chamber resistance on the gas generator peak temperature is shown to be small for these two firings. Table IX shows that firing 02A test conditions were closely duplicated on firing 04E except for the desired single variable, thrust chamber temperature at engine start. There was a difference of 110°F in thrust chamber temperature at $t_0$ for these two firings. Gas generator peak temperatures differed by only 120°F, showing roughly a 1:1 correlation between decreased thrust chamber temperature and increased gas generator peak temperature. The assumption has been made that the reorificing of the engine between these two firings had no appreciable effect on this conclusion. Orifice sizes used for these two firings were as follows:

| Gas Generator | Firing 02A | Firing 04E | Area Increase, percent |
|---|---|---|---|
| Fuel Orifice Diameter, in. | 0.472 | 0.500 | 12.1 |
| Oxidizer Orifice Diameter, in. | 0.276 | 0.294 | 13.5 |

The difference in gas generator ignition characteristics caused by decreased thrust chamber resistance resulted in a slower thrust chamber pressure buildup rate to main-stage operation on firing 04E than on firing 02A. Thrust chamber pressure buildup time to 550 psia required 31 msec longer on firing 04E as a result of the delayed gas generator ignition and lower gas generator power as bootstrap operation began. Figures 27a and e show the effect that thrust chamber resistance had on engine buildup time. The difference in fuel pump discharge pressure (shaded area in Fig. 27d) for identical fuel pump spinup rates (Fig. 27e) is the result of thrust chamber resistance to fuel flow. The difference in fuel pump speed rise rates shown in Fig. 27e after gas generator ignition is indicative of the slower gas generator power buildup rate on firing 04E. The corresponding difference in fuel pump discharge pressure after gas generator ignition reflects this difference in fuel pump speed.

## 4.5 ENGINE PERFORMANCE

Engine steady-state performance data are presented in Table X for a 1-sec data average between 29 and 30 sec after $t_0$ for firings 04A, 04C, and 04E. These data were computed using the Rocketdyne PAST 640, modification zero, performance computer program. Engine test measurements required by the program and the program computations are presented in Appendix IV. Data from the flight instrumentation sensor for oxidizer turbine inlet pressure (POTI-1A) were nonrecoverable for any of the subject firings. A value of 3.0 psia was added to the oxidizer turbine bypass nozzle (PGBNI) pressure measurement during each of these tests, and this estimated pressure was substituted for the missing POTI-1A measurement. The 3-psi value represented a mean difference between these two values measured during previous firings and the exact difference measured for this particular fuel turbine during test J4-1801-01 (Ref. 7).

The engine was reorificed between tests J4-1801-03 and -04 (see Table II) to compensate for significant reduction in fuel turbine blade area caused by erosion during test J4-1801-03. The normalized performance data (Table X) show that overall engine performance was higher than nominal during firings 04A and 04C and very close to nominal during firing 04E. For rated conditions (not presented in Table X) of 225,000-$lb_f$ thrust, 5.50 mixture ratio, and 1200°F fuel turbine inlet temperature, test data show that the oxidizer turbine bypass nozzle and the gas generator oxidizer supply orifice were slightly undersized by 2 and 0.5 percent, respectively. The gas generator fuel supply orifice was correctly sized.

Site data presented in Table X show that combustion chamber pressure and calculated engine thrust were decreased proportionately to lower gas generator chamber pressure during the 1-sec data average of each successive firing. The lower gas generator chamber pressure on successive firings resulted from lowered gas generator mixture ratio (evidenced by corresponding decreased fuel turbine inlet temperature). Calculated fuel turbine efficiency was only slightly below nominal. Calculated oxidizer turbine efficiency was slightly above nominal.

### 4.6 AUGMENTED SPARK IGNITER OPERATION

Pump inlet pressures were set at the extreme limits of the safe starting regions, high oxidizer and low fuel pressures, for firings 04A, 04B, and 04E (see Fig. 17). These are the conditions most conducive to yield excessive combustion temperature in the augmented spark igniter and erosion of the igniter chamber. A 0.110-in.-diam augmented spark igniter oxidizer supply line orifice was installed for these firings. The absence of any erosion as determined from post-test physical examination was the basis of the conclusion that augmented spark igniter operation was completely satisfactory during these firings. A previous AEDC firing, J4-1554-19 (Ref. 8), produced severe erosion using a 0.150-in.-diam oxidizer supply line orifice with the same relative pump inlet pressures. The subject firings indicate that a 0.110-in.-diam oxidizer supply line orifice precludes the occurrence of the undesirable high igniter chamber temperatures.

### 4.7 POST-TEST INSPECTION

Following test J4-1801-04, the fuel and oxidizer turbines were disassembled for inspection. This inspection showed the oxidizer turbine to be in satisfactory condition, and it was reinstalled on the engine. However, inspection of the fuel turbine showed that it would have to be replaced. There were five known cracks in the fuel turbine curvic coupling before the subject test. Two additional cracks developed during this test period, and the five original cracks progressed as indicated in Fig. 28.

Measurements of the amount of material that had eroded from the blades of the fuel turbine first stage, taken before and after the subject test, showed that no significant erosion occurred during these four firings. Figure 29 shows the eroded condition of the fuel turbine

as compared with the worst of the eroded blades from the turbine that had been damaged during the anomalous test J4-1554-30.

Because of the suspected oxidizer leakage from the gas generator after engine cutoff of firing 04A, the gas generator control valve was removed from the engine for extensive post-test physical examination by the engine manufacturer.

# SECTION V
# SUMMARY OF RESULTS

The results of the four J-2 engine firings obtained and the fifth firing attempt on August 3, 1967, in Test Cell J-4 during test period J4-1801-04 are summarized as follows:

1. Variations in gas generator oxidizer supply line pre-fire conditioning were shown to have significant effects of up to 500°F on gas generator outlet peak temperature.
2. A red line limit was established for gas generator oxidizer supply line thermal conditions at engine start. Restart firing attempt 04D was aborted because these conditions were realized.
3. An abnormally high gas generator outlet temperature (1860°F), 4 sec after shutdown of firing 04A, indicated probable leakage from the gas generator oxidizer poppet.
4. A minimum starting energy S-V/S-IVB restart firing was successfully conducted. The minimum high level stall margin for the fuel pump was approximately 600 gpm. Thrust chamber pressure buildup time to the 550-psia level was the slowest to date observed in AEDC altitude testing — 2.758 sec.
5. A maximum starting energy S-V/S-IVB restart firing was made with minimum model specification fuel pump inlet pressure at the crossover duct temperature level predicted for 80-min (first orbit) restart. Conservative low level fuel pump stall margin (over 1300-gpm) was maintained.
6. Thrust chamber resistance to fuel flow was found to have a small effect on gas generator peak temperature during two maximum starting energy S-V/S-IVB first burn firings, which were made at the opposite extremes of thrust chamber pre-chill predicted for S-V flight.

7. Normalized engine steady-state performance data computed for three 30-sec firings (04A, 04C, and 04E) showed that overall engine performance was higher than nominal on firings 04A and 04C and close to nominal on firing 04E.

8. Augmented spark igniter operation was satisfactory during all firings. A 0.110-in.-diam oxidizer supply line orifice was used. Pump inlet pressures were set at engine start of firings 04A, 04B, and 04E for worst-case expected igniter chamber erosion.

9. Vibration safety cutoff counts were measured during thrust chamber ignition of three of the firings (04A, 04C, and 04E) with durations ranging from 15 to 97 msec.

## REFERENCES


1. Dubin, M., Sissenwine, N., and Wesler, H. U. S. Standard Atmosphere, 1962. December 1962.
2. Kunz, C. H. "Altitude Testing of the J-2 Rocket Engine in Propulsion Engine Test Cell (J-4) (Test J4-1801-03)." AEDC-TR-67-209, December 1967.
3. "J-2 Rocket Engine, Technical Manual Engine Data", R-3825-1, August 1965.
4. Test Facilities Handbook (6th Edition). "Large Rocket Facility, Vol. 3." Arnold Engineering Development Center, November 1966.
5. Franklin, D. E. "Altitude Testing of the J-2 Rocket Engine in Propulsion Engine Test Cell (J-4) (Test J4-1801-02)." AEDC-TR-67-192, December 1967.
6. Collier, M. R., and Dougherty, N. S., Jr. "Altitude Testing of the J-2 Rocket Engine in Propulsion Engine Test Cell (J-4) (Tests J4-1554-20 through J4-1554-26)." AEDC-TR-67-145, October 1967.
7. Muse, W. W., and Pillow, C. E. "Altitude Testing of the J-2 Rocket Engine in Propulsion Engine Test Cell (J-4) (Test J4-1801-01)." AEDC-TR-67-181, December 1967.
8. Simpson, J. N., Cantrell, F. D., and Kunz, C. H. "Altitude Testing of the J-2 Rocket Engine in Propulsion Engine Test Cell (J-4) (Tests J4-1554-12 through J4-1554-19)." AEDC-TR-67-115 (AD820463), September 1967.

## APPENDIXES

I. ILLUSTRATIONS
II. TABLES
III. INSTRUMENTATION
IV. METHODS OF CALCULATIONS (PERFORMANCE PROGRAM)

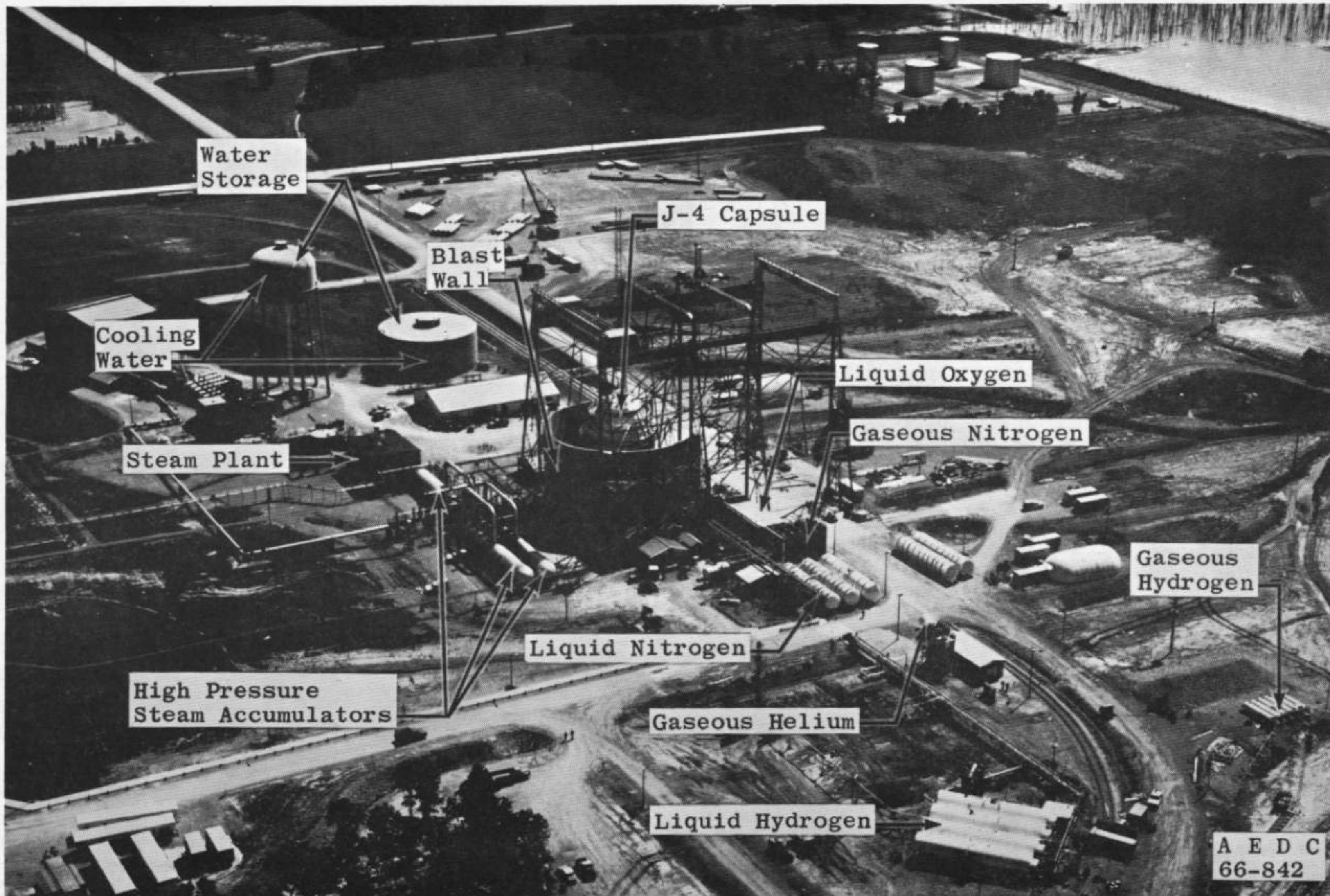



Fig. 1 Test Cell J-4 Complex

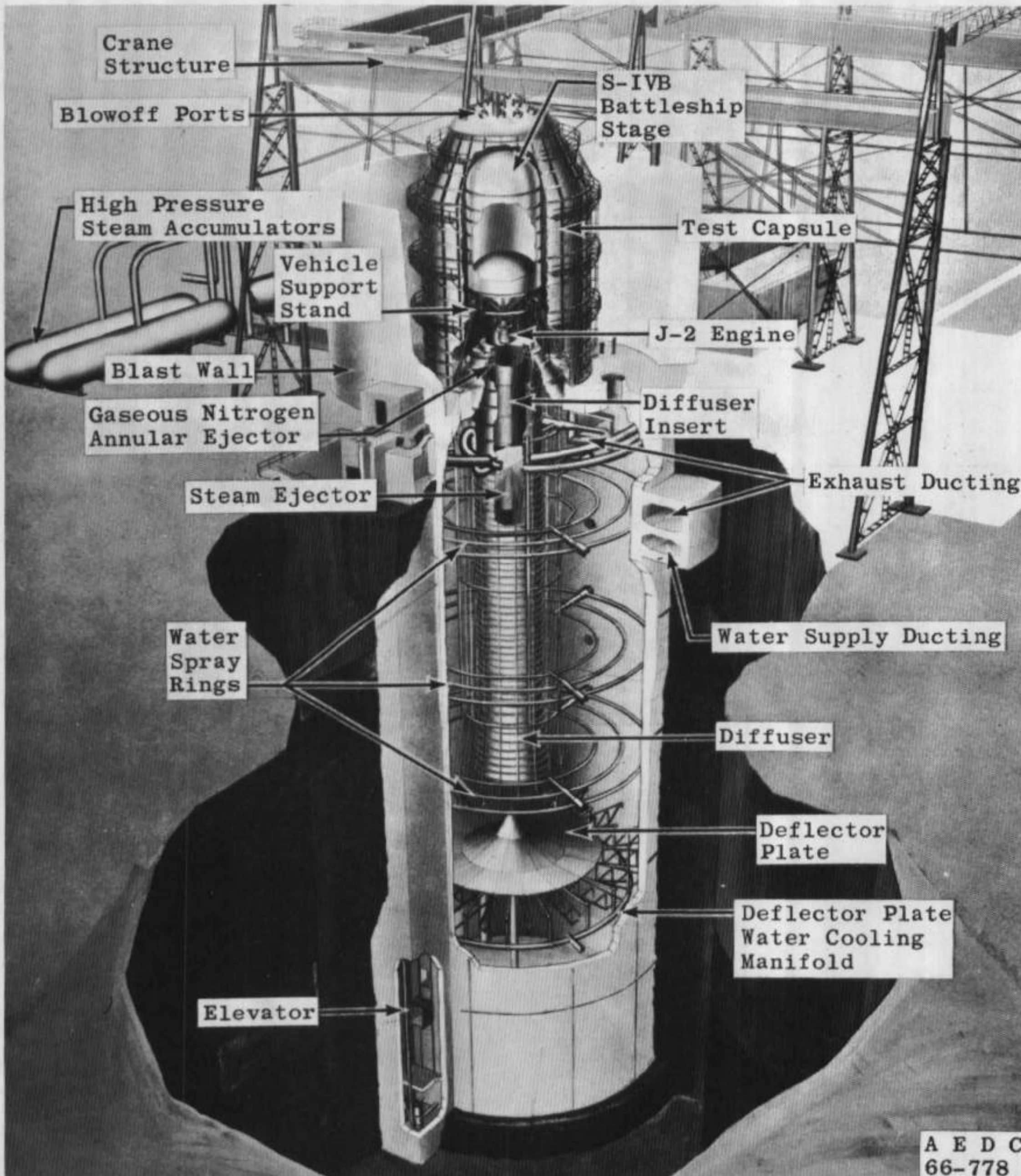



**Fig. 2 Test Cell J-4, Artist's Conception**

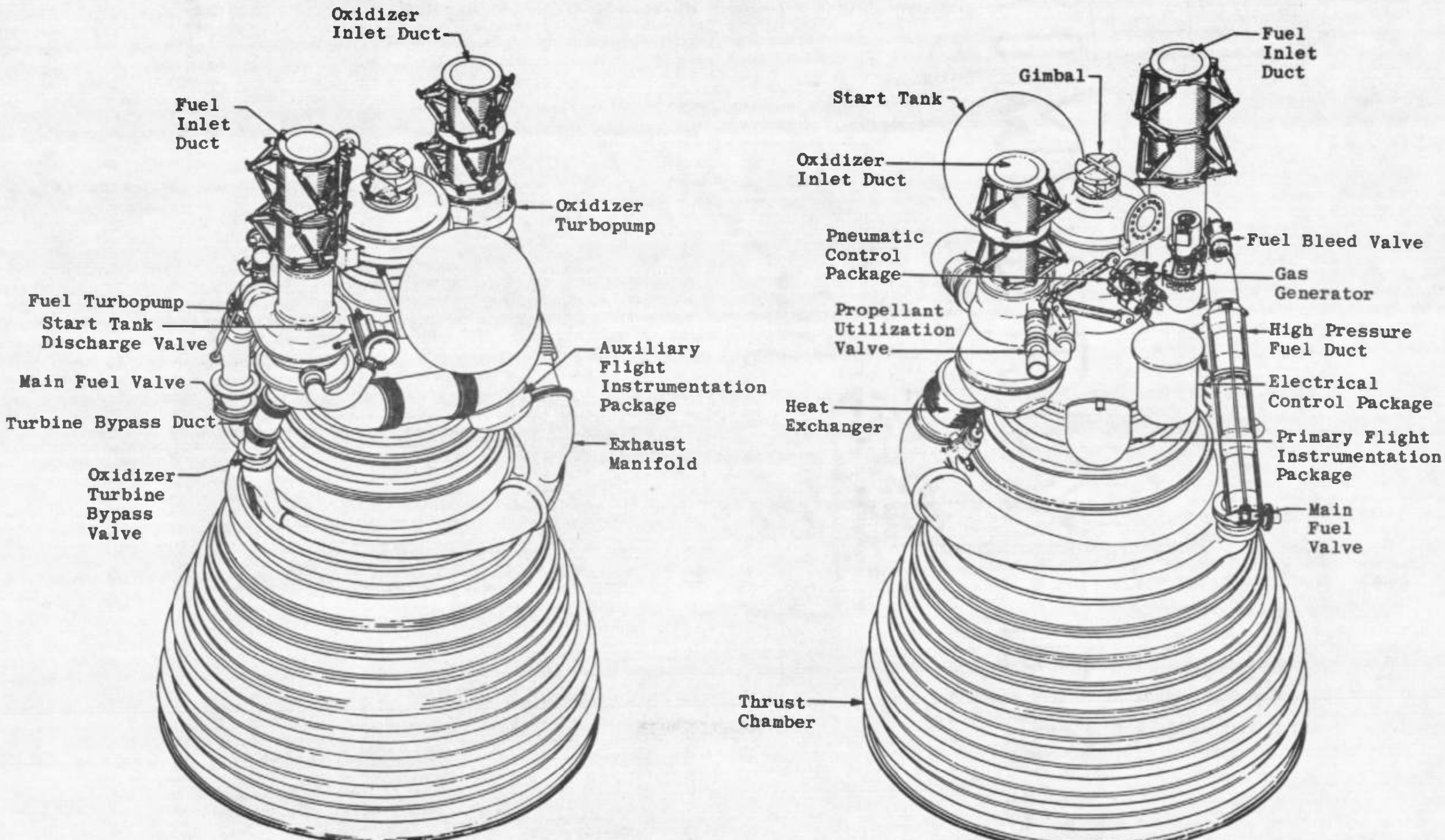



Fig. 3 Engine Details

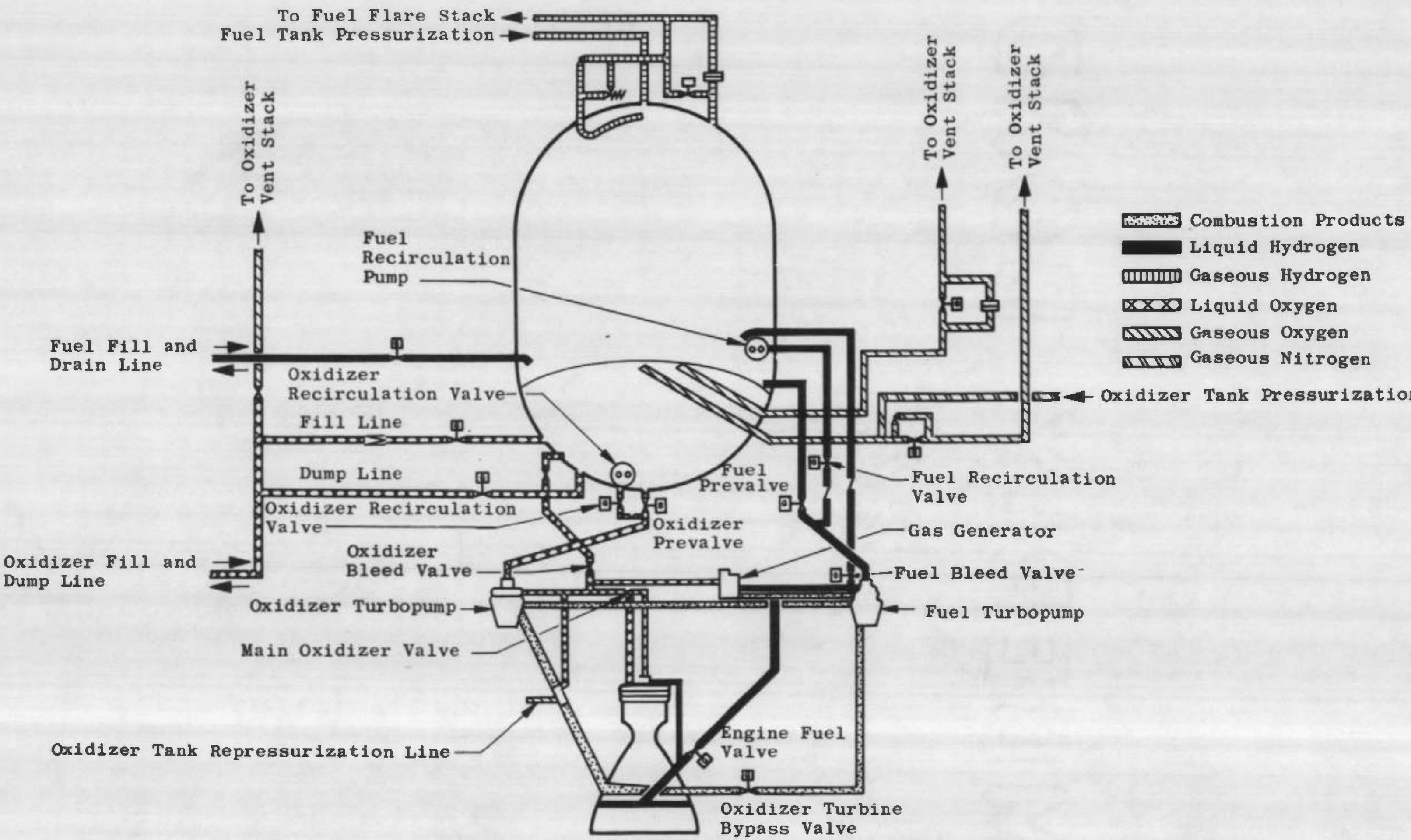



Fig. 4 S-IVB Battleship Stage/J-2 Engine Schematic

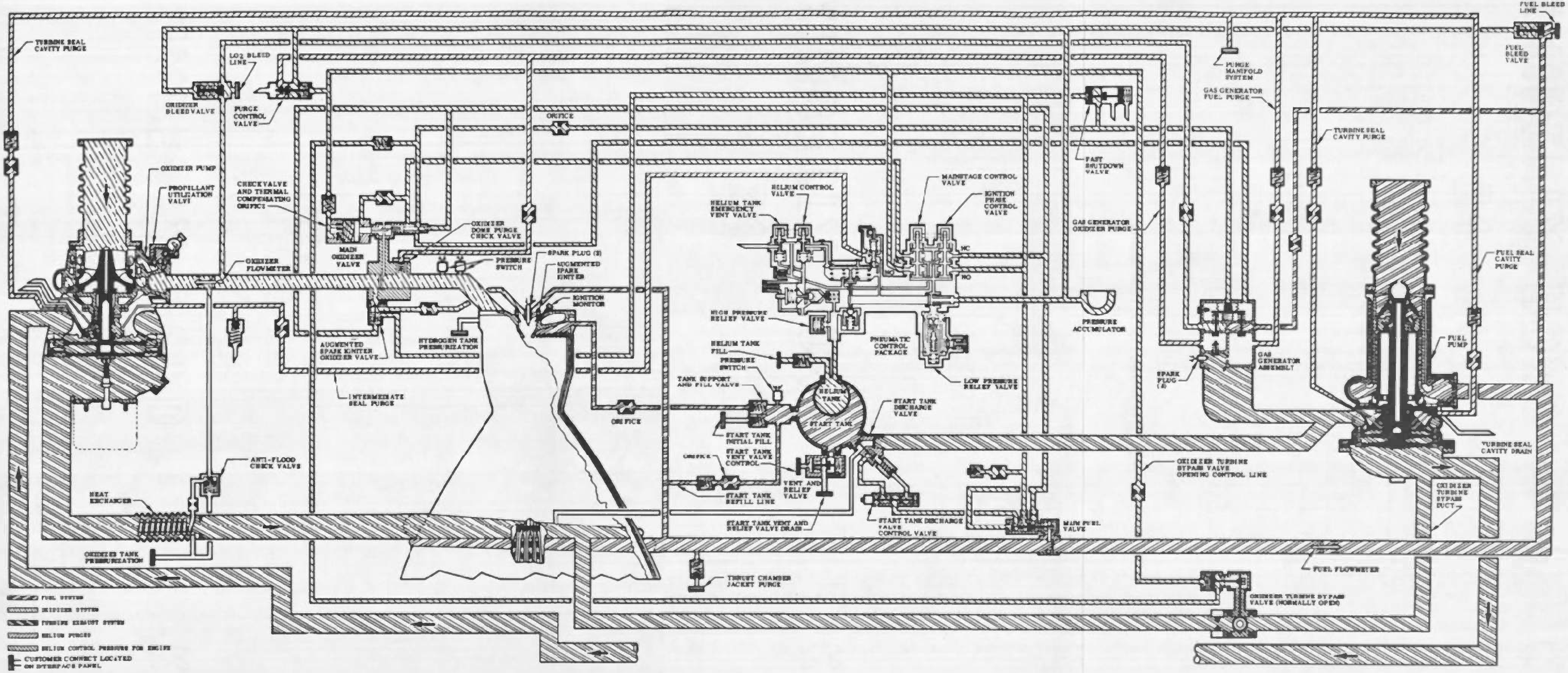



Fig. 5 Engine Schematic

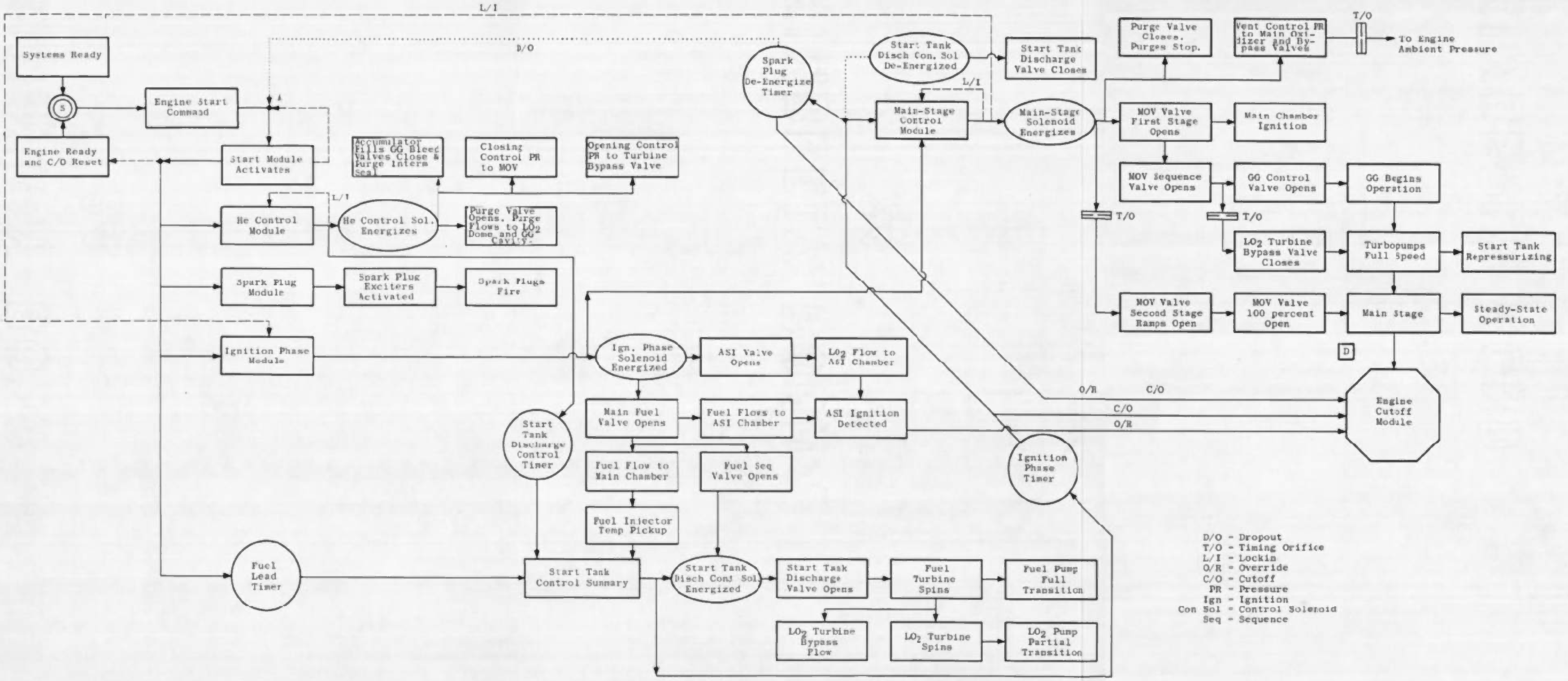
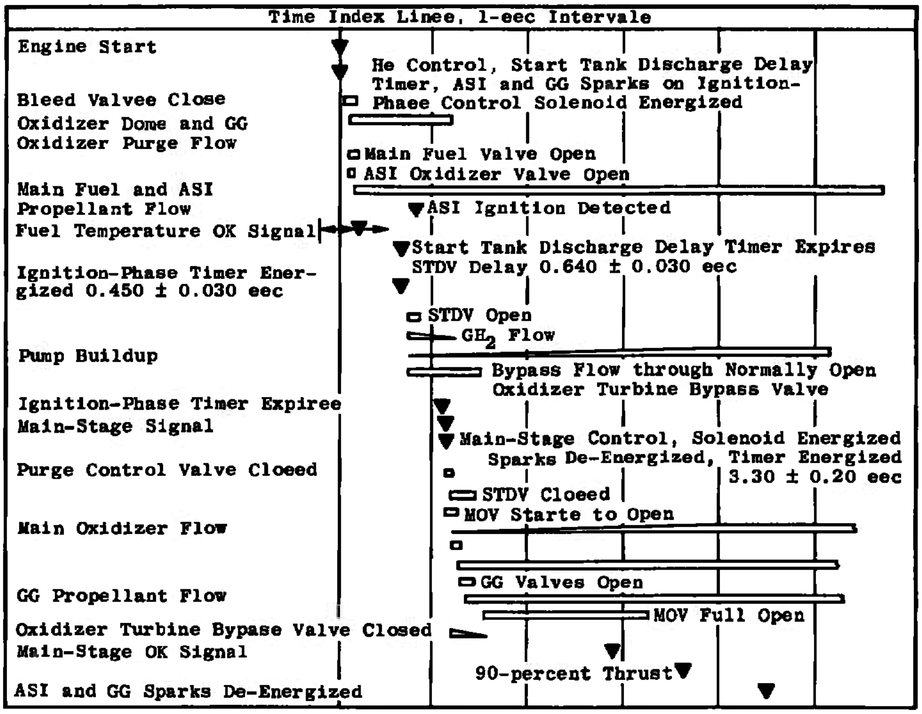
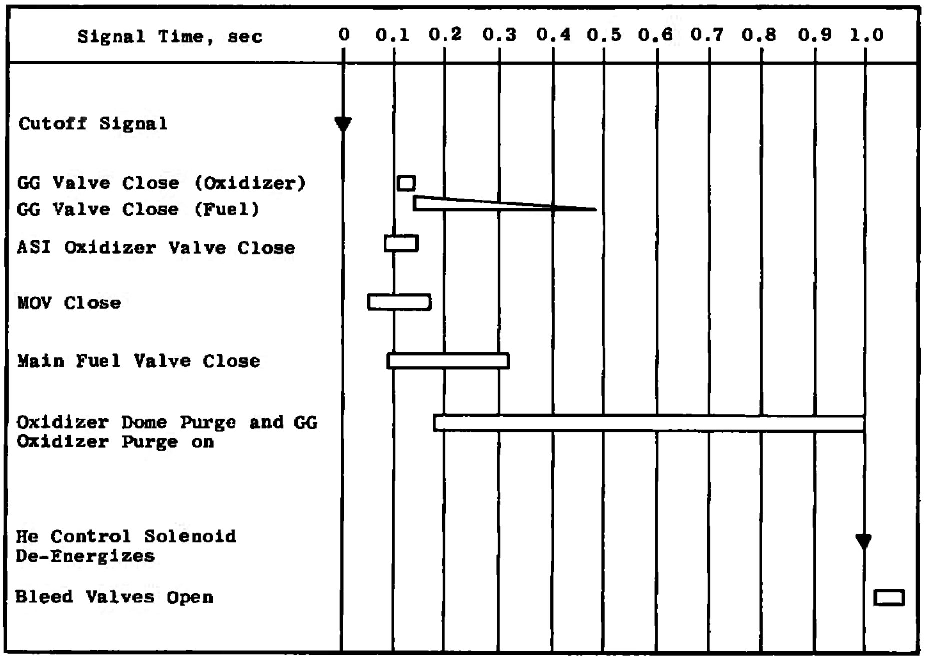



Fig. 6 Engine Start Logic Schematic

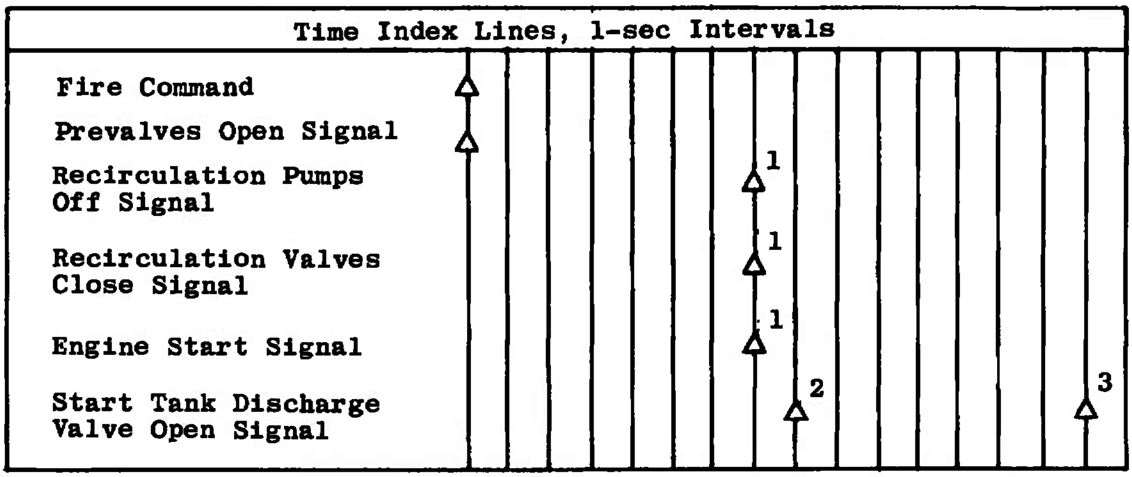



**a. Start Sequence**



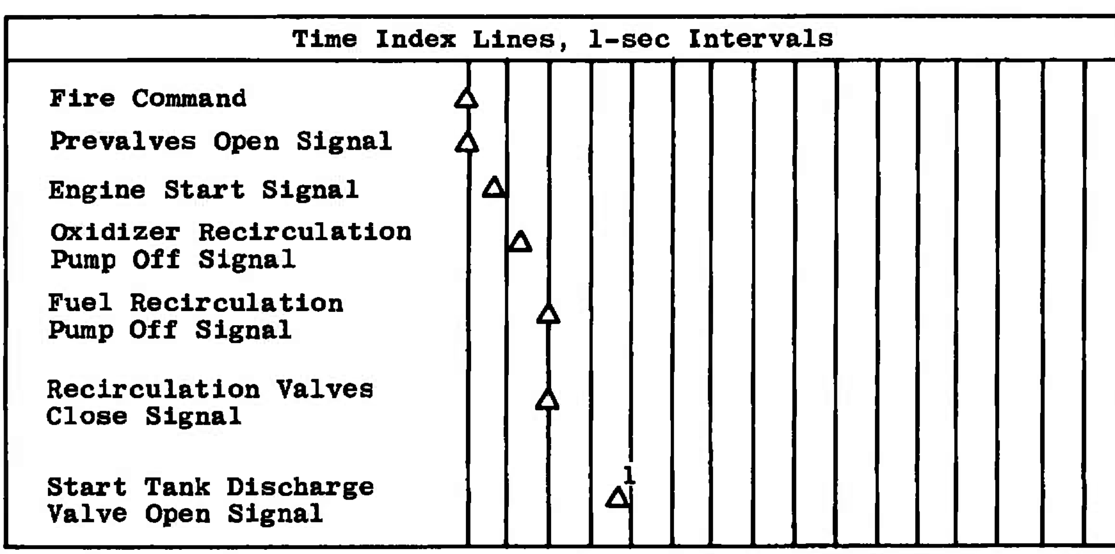

**b. Shutdown Sequence**

**Fig. 7 Engine Start and Shutdown Sequence**




[1]Nominal Occurrence Time (Function of Prevalves Opening Time)
[2]One-sec Fuel Lead (S-II/S-V and S-IVB/S-IB)
[3]Eight-sec Fuel Lead (S-IVB/S-V and S-IB Orbital Restart)

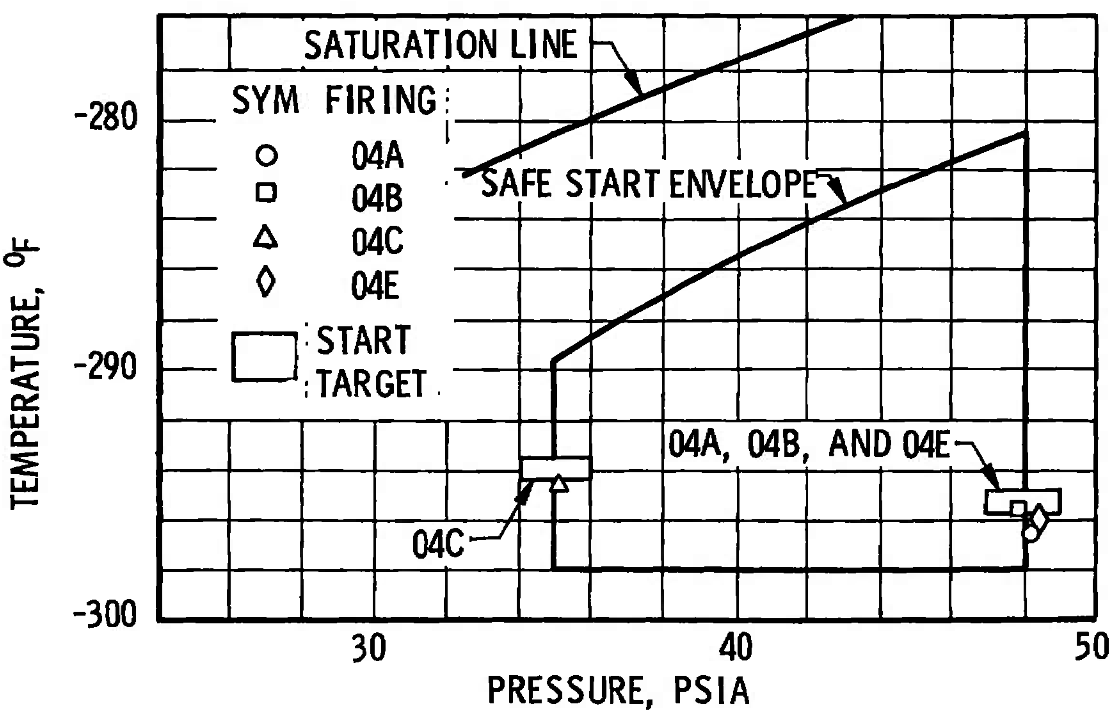
c. Normal Logic Start Sequence



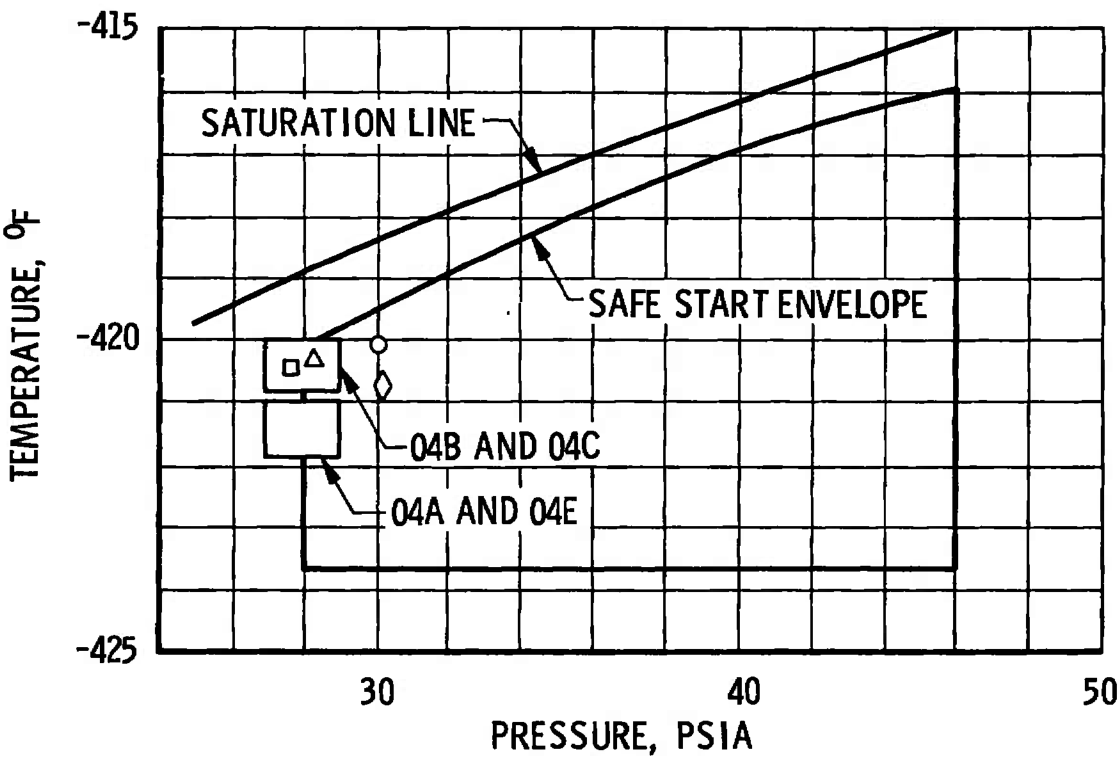

[1]Three-sec Fuel Lead (S-IVB/S-V First Burn)

d. Auxiliary Logic Start Sequence

Fig. 7 Concluded

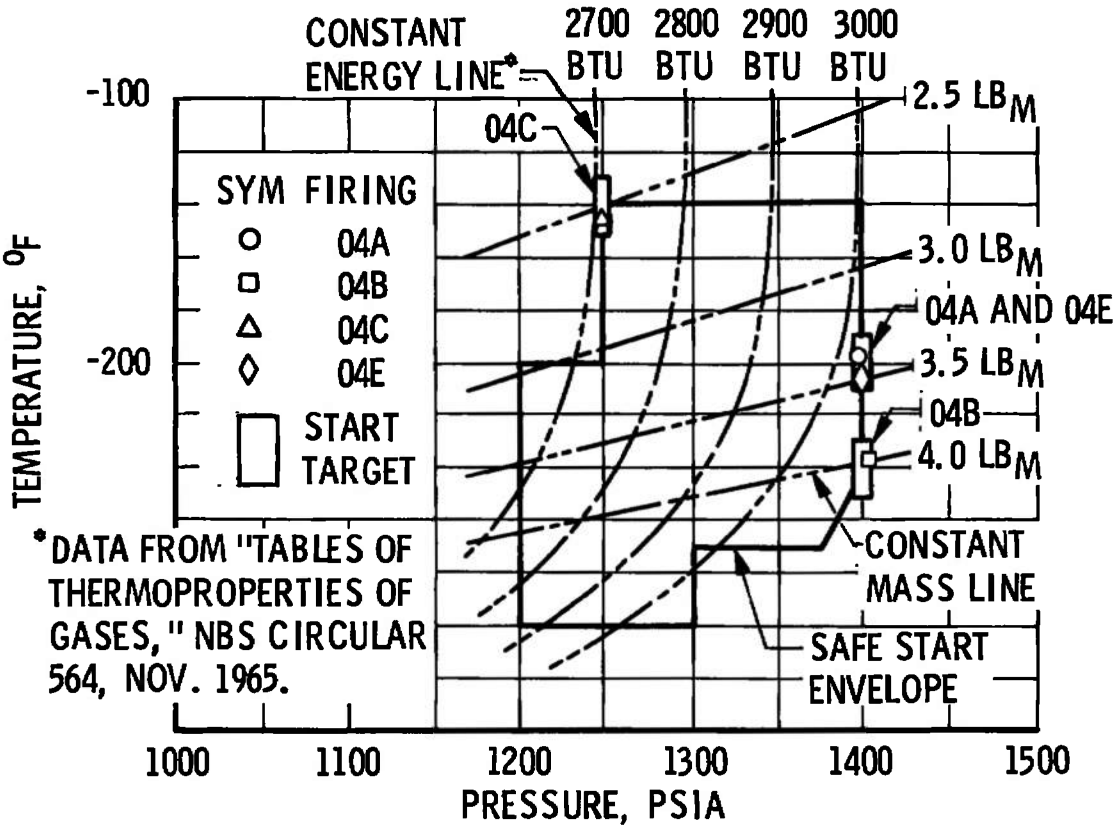



a. Oxidizer Pump Inlet

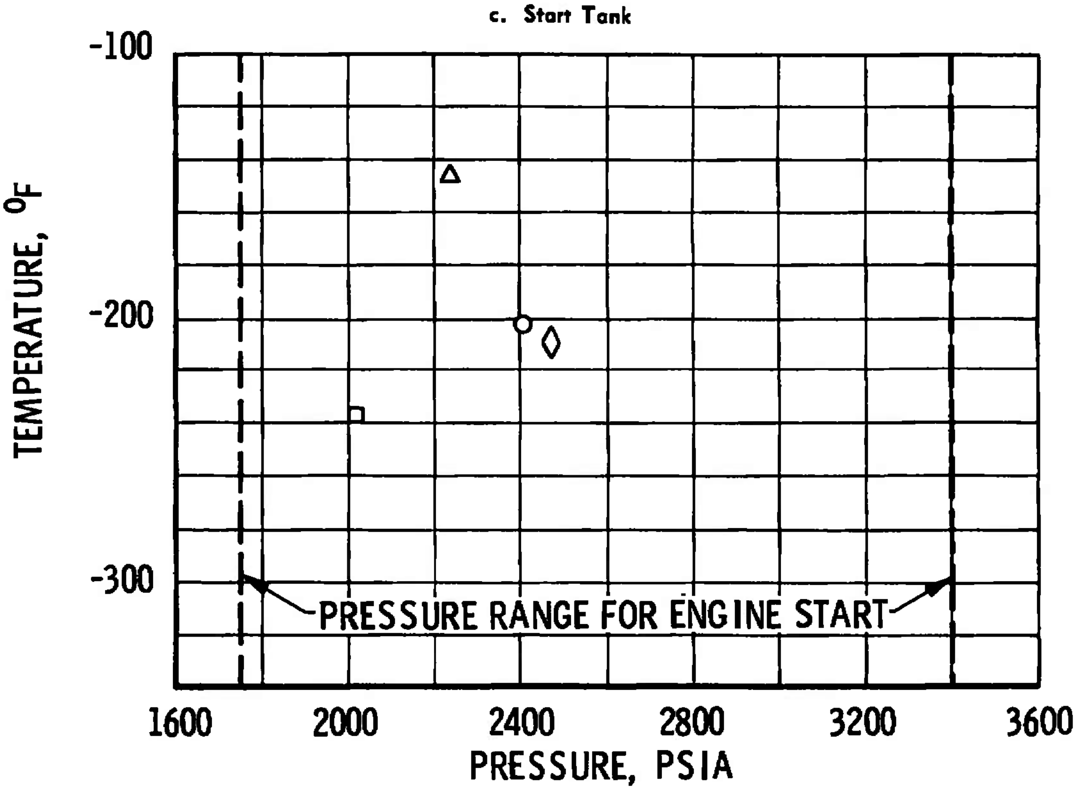



b. Fuel Pump Inlet

Fig. 8 Engine Start Conditions for Pump Inlets, Start Tank, and Helium Tank

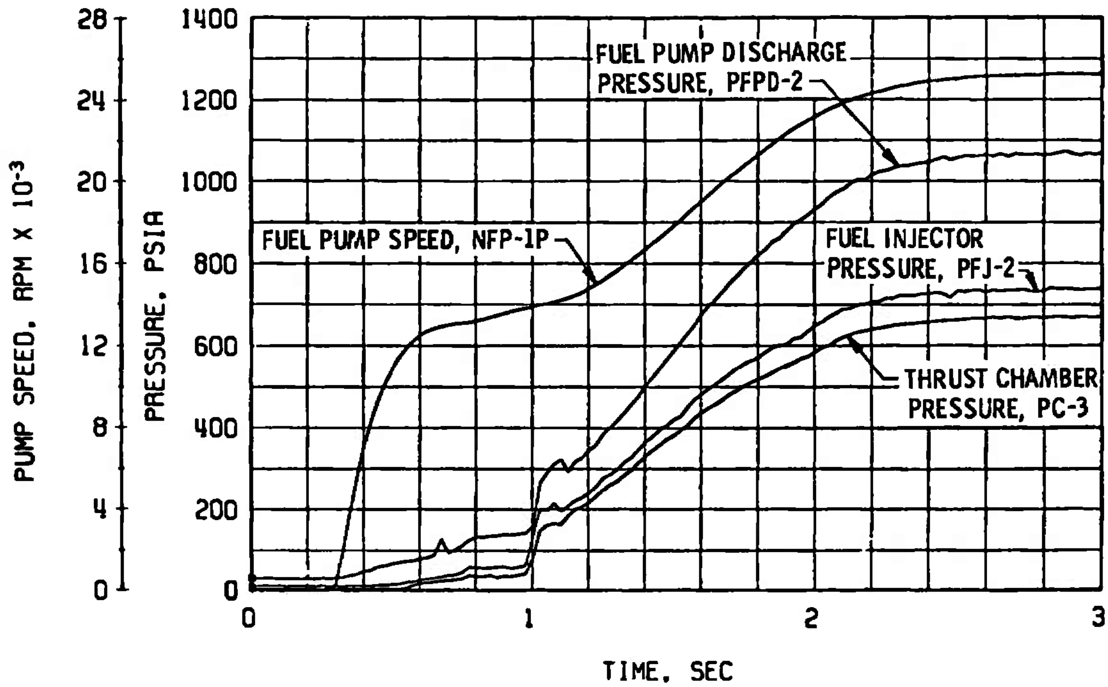



c. Start Tank

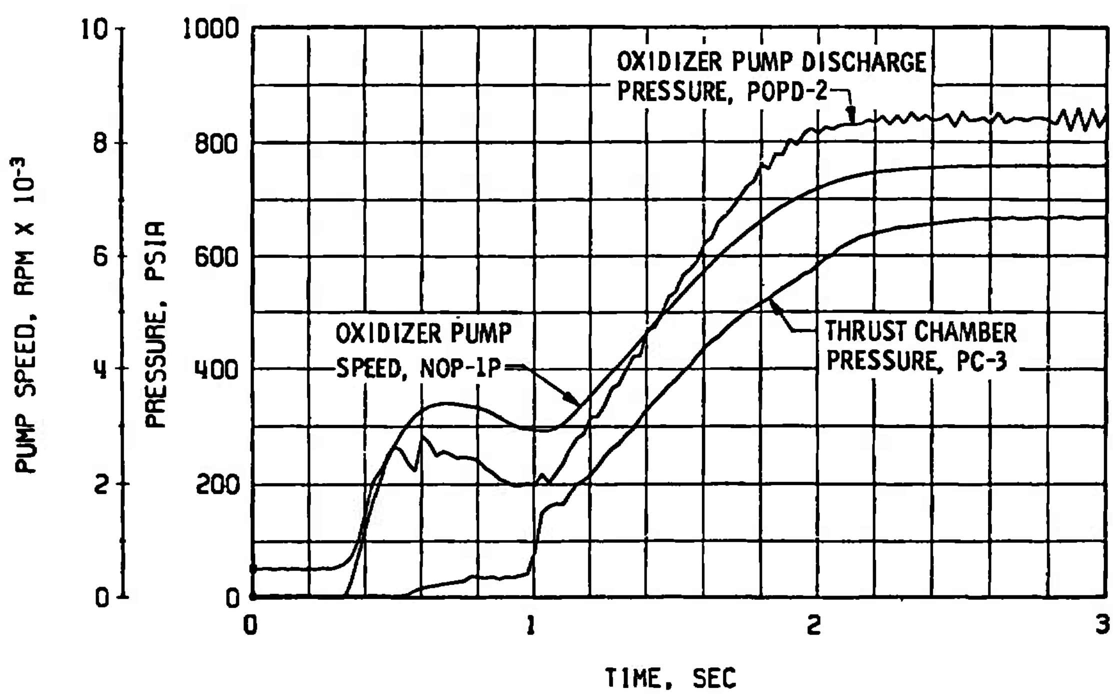



d. Helium Tank

Fig. 8 Concluded

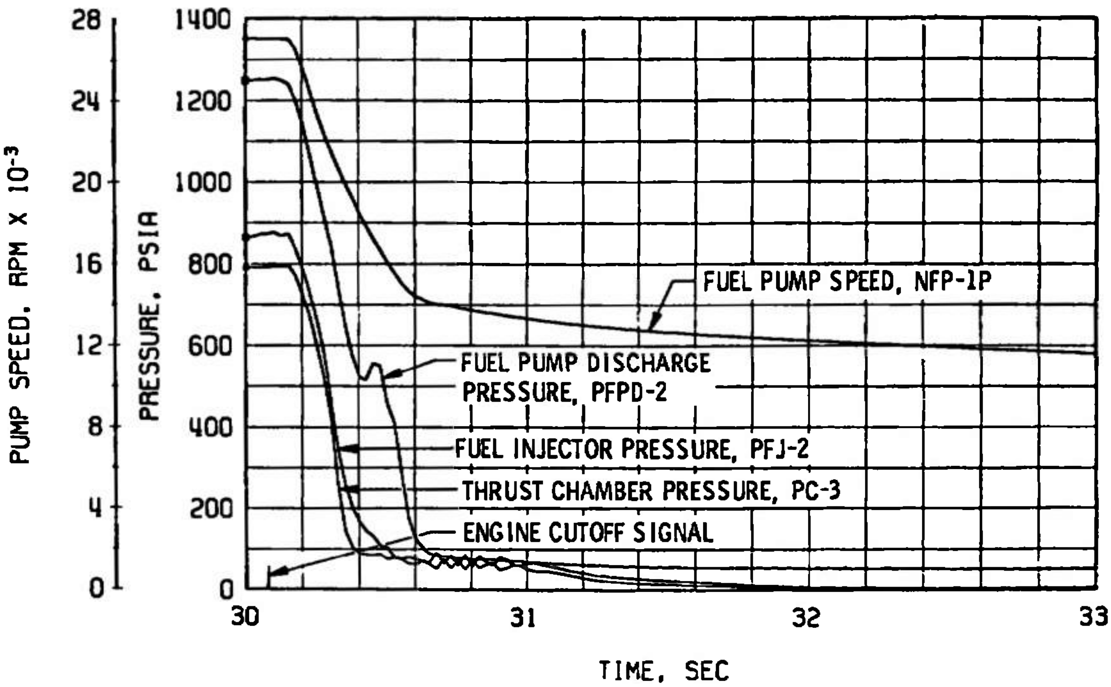



a. Start Transient, Thrust Chamber Fuel System

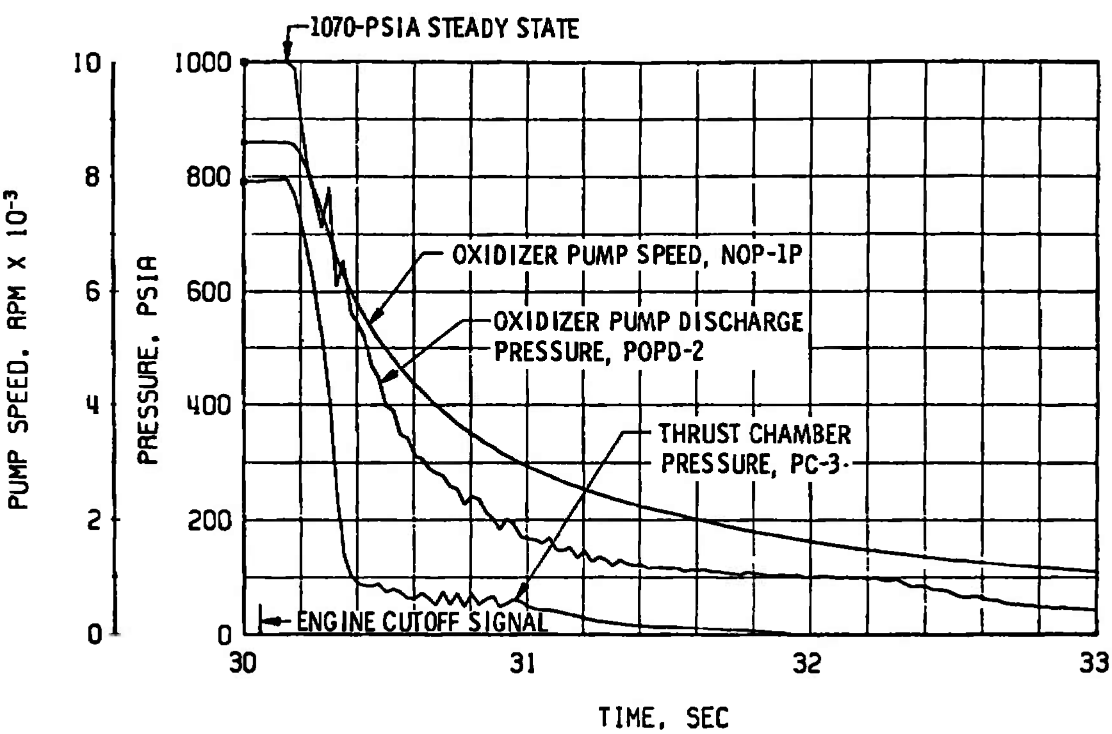



b. Start Transient, Thrust Chamber Oxidizer System

Fig. 9 Engine Transient Operation, Firing 04A

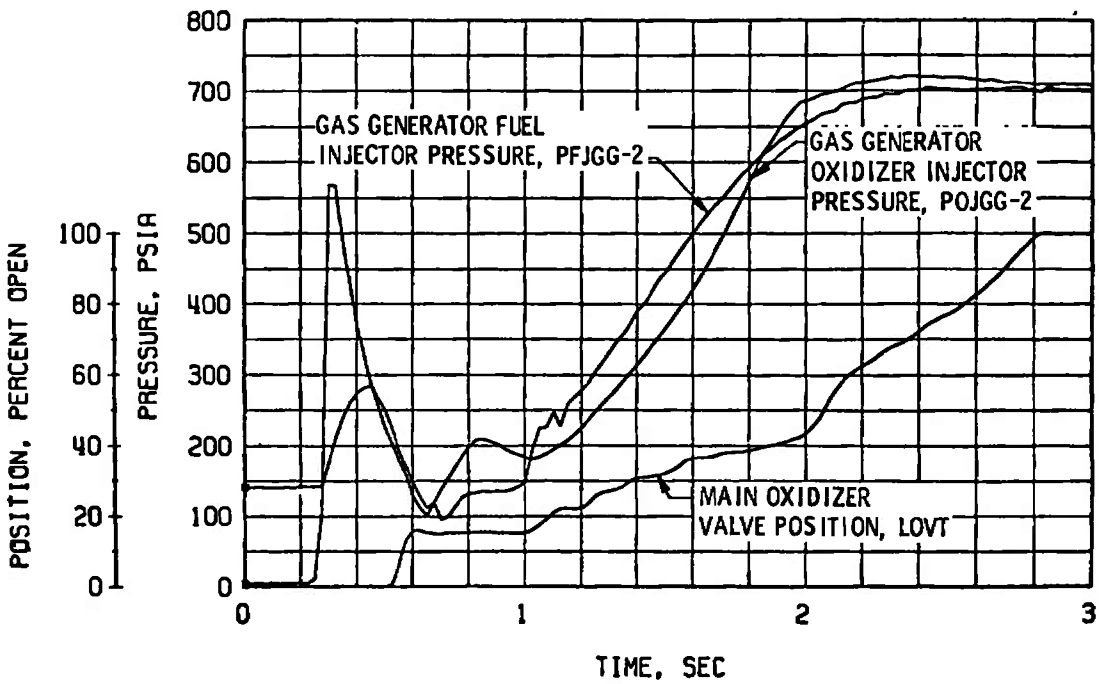


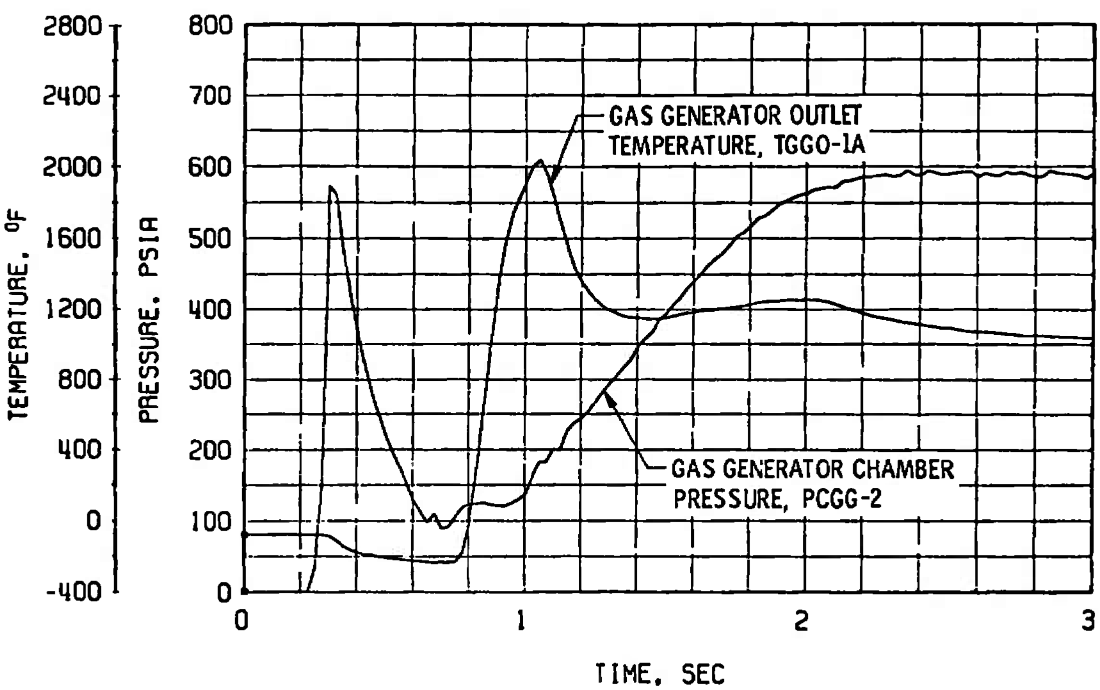

c. Shutdown Transient, Thrust Chamber Fuel System




d. Shutdown Transient, Thrust Chamber Oxidizer System

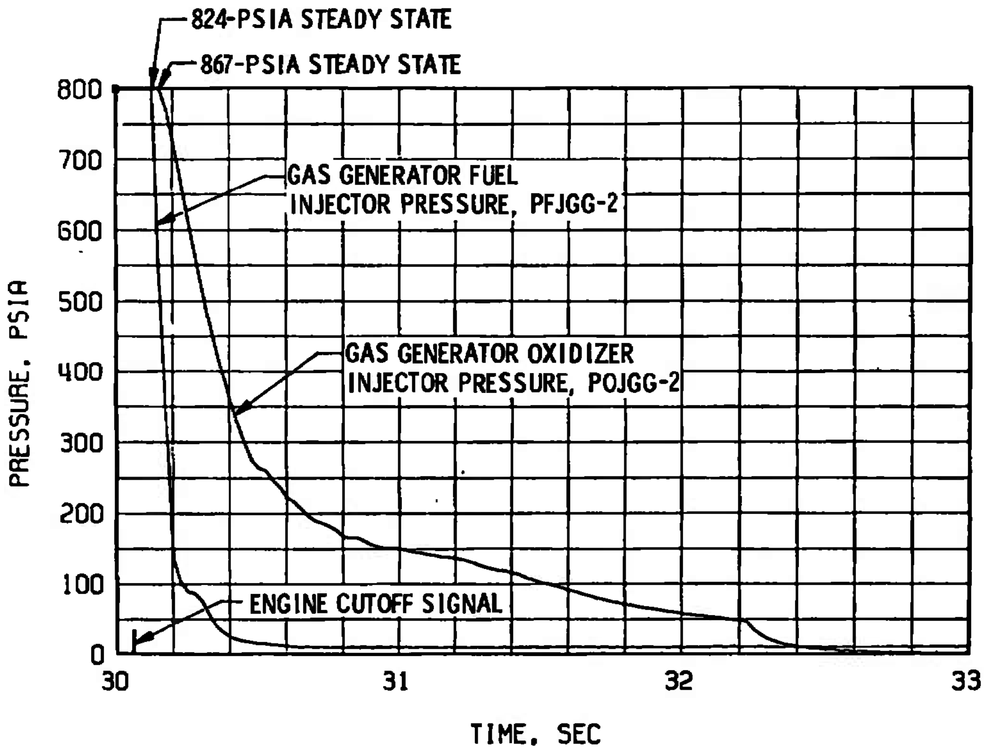
Fig. 9 Continued

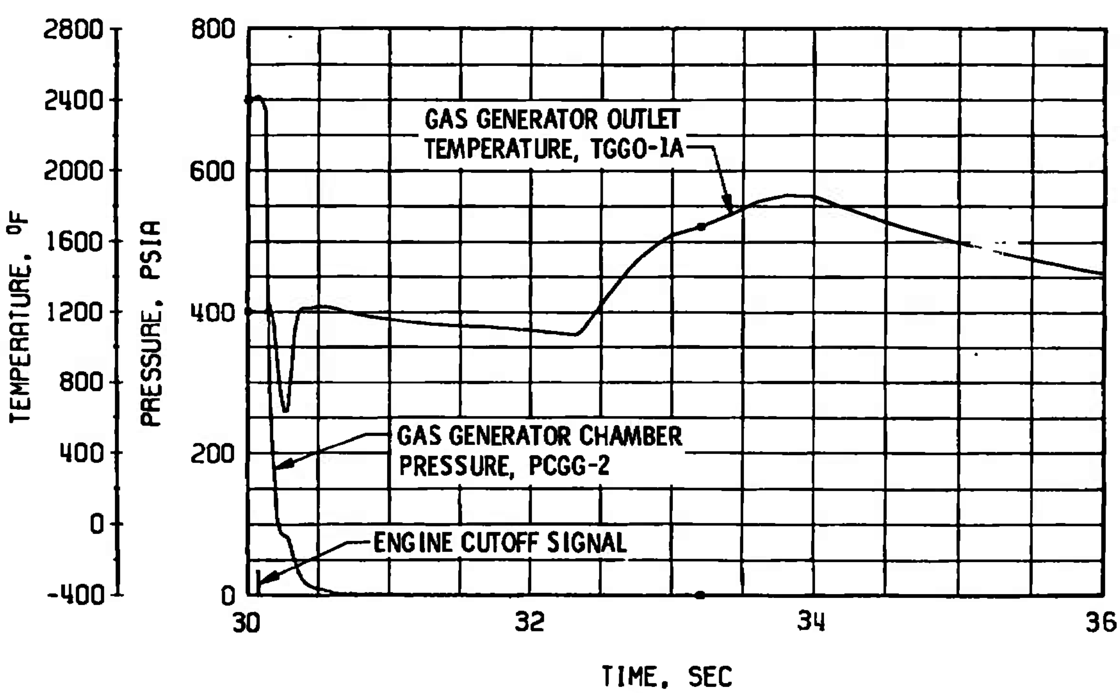



e. Start Transient, Gas Generator

Fig. 9 Continued




f. Shutdown Transient, Gas Generator

Fig. 9 Concluded

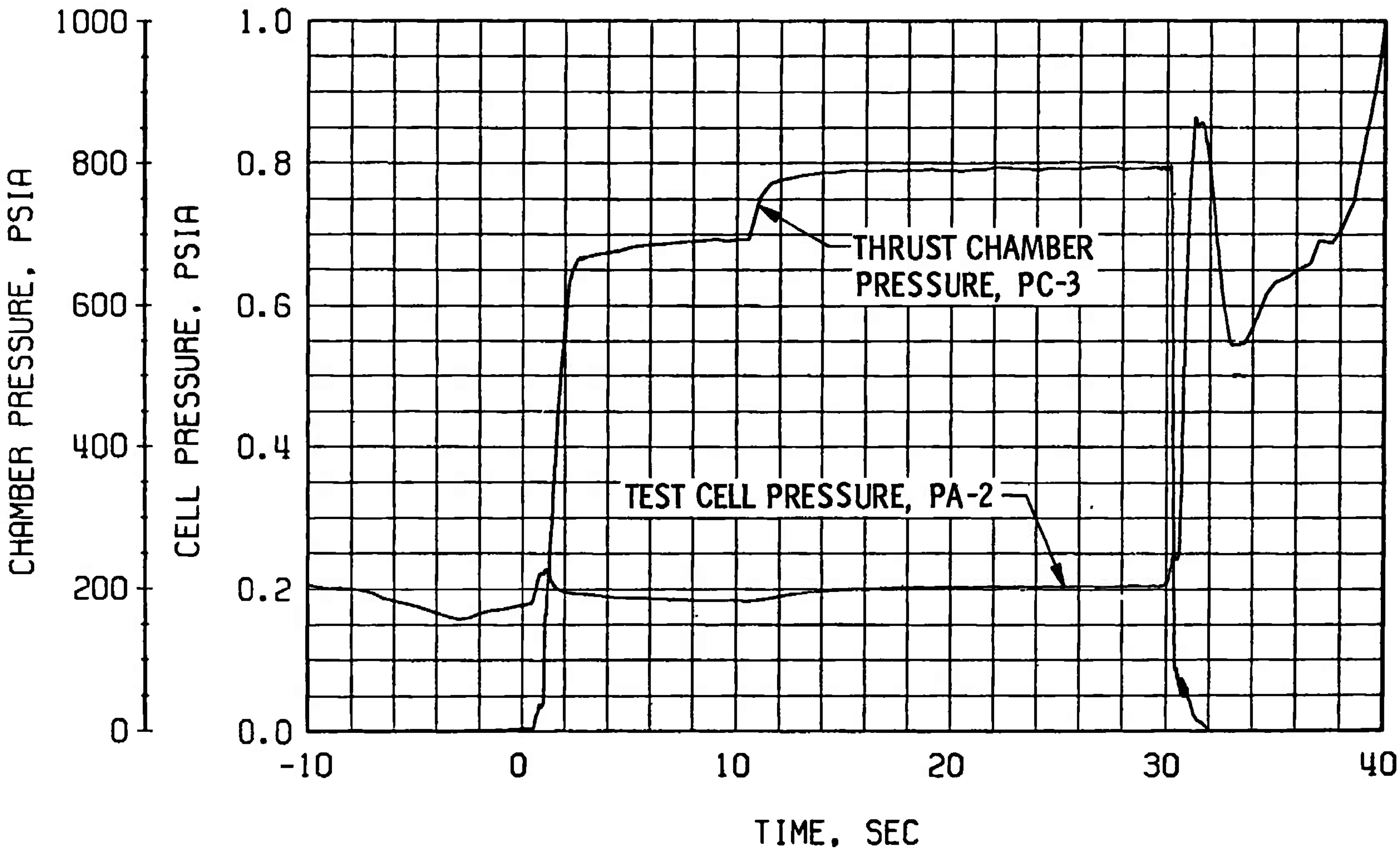
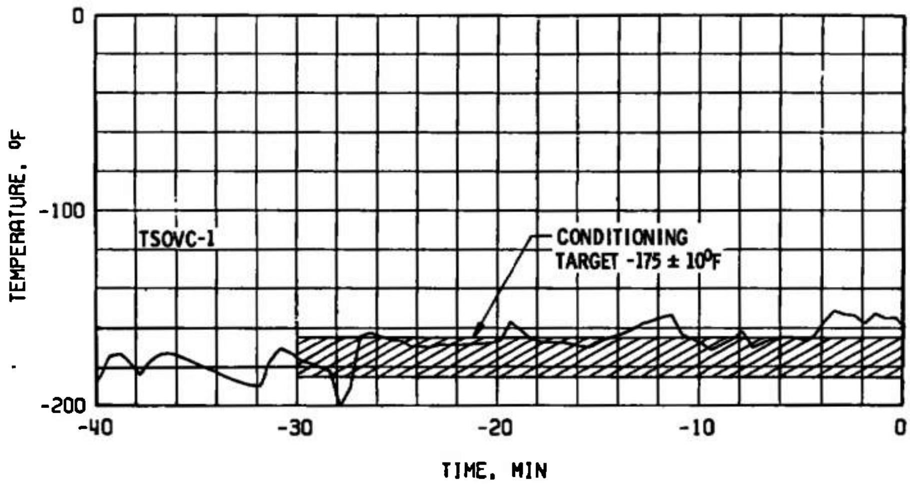
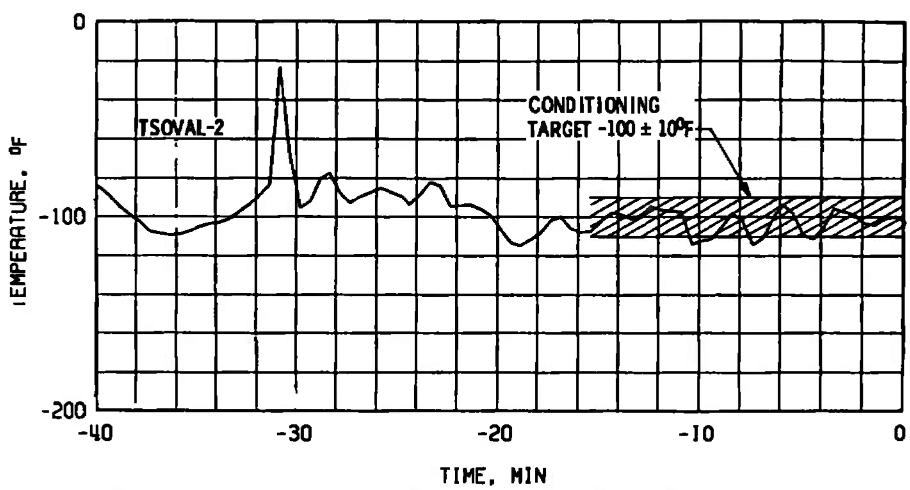


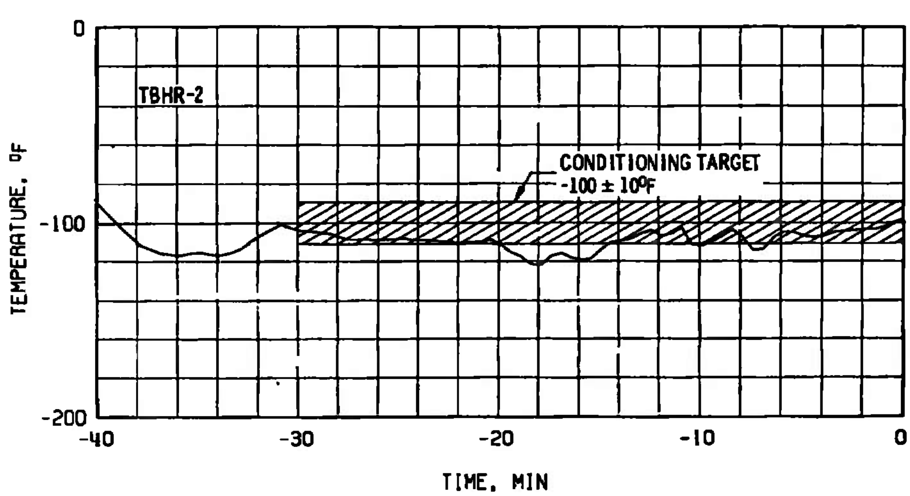

**Fig. 10 Engine Ambient and Combustion Chamber Pressures, Firing 04A**




a. Main Oxidizer Valve Second-Stage Actuator Conditioning

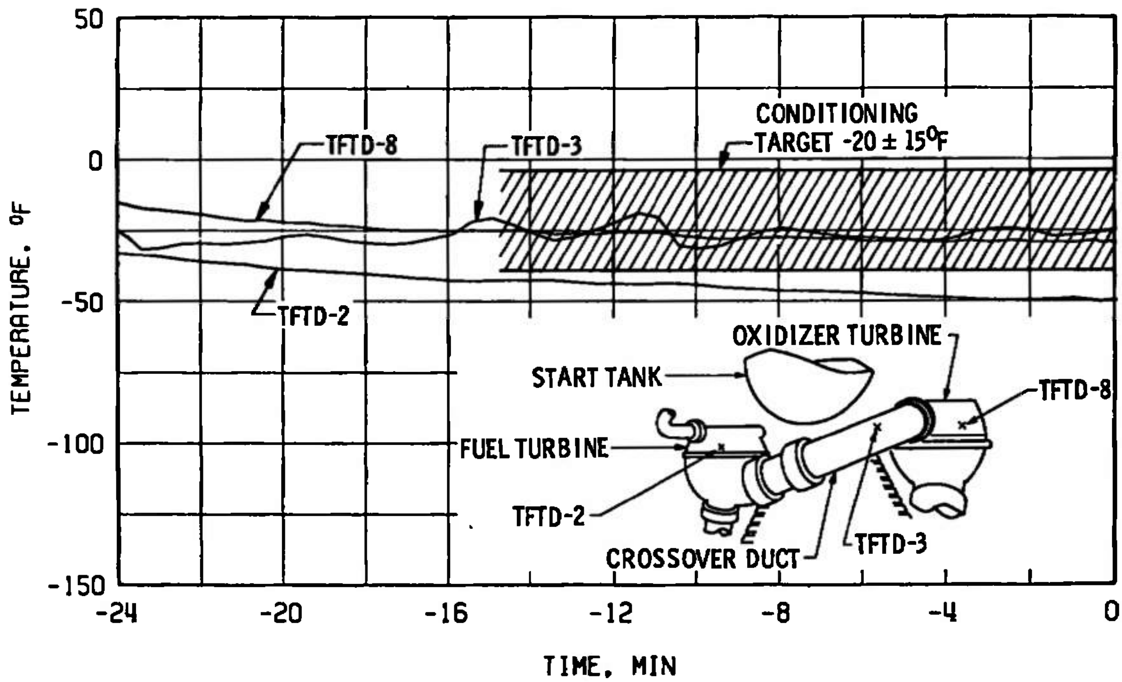



b. Main Oxidizer Valve Closing Control Line Conditioning

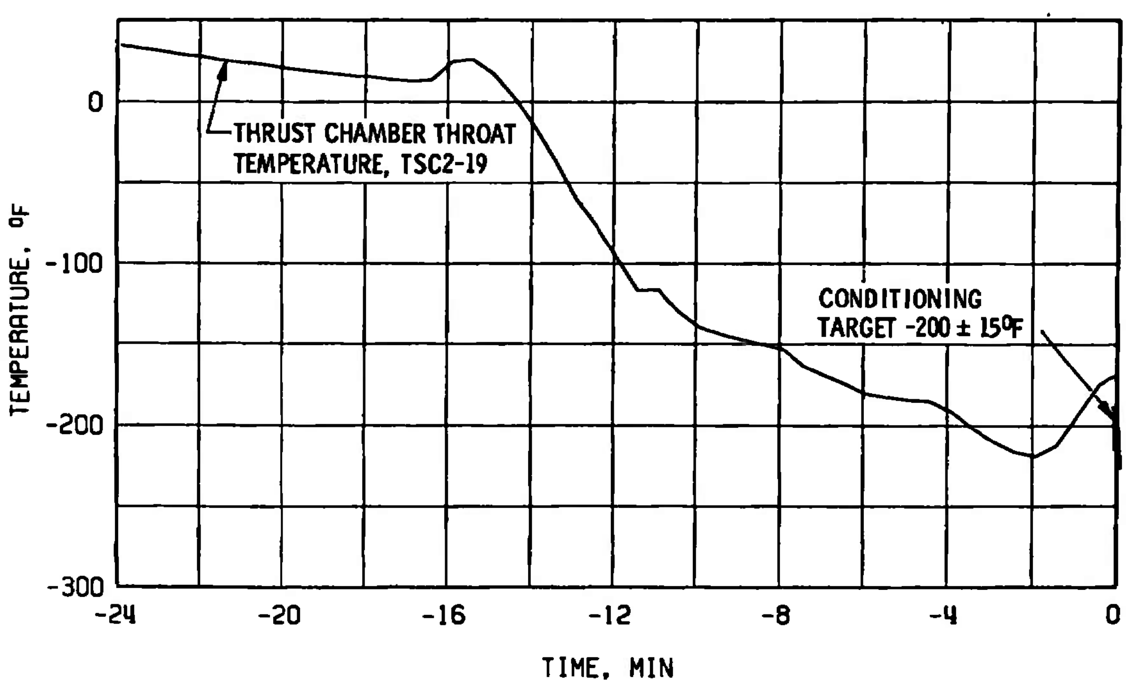



c. Pneumatic Control Package Conditioning

Fig. 11 Thermal Conditioning History of Engine Components, Firing 04A

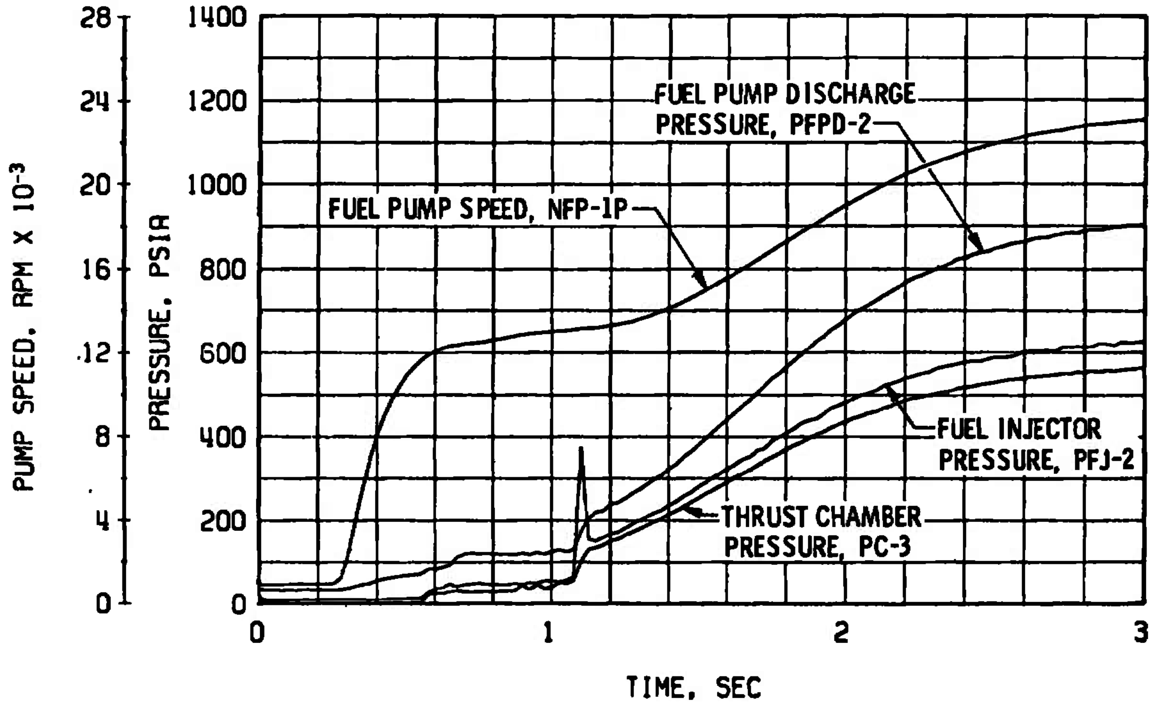



d. Crossover Duct Conditioning

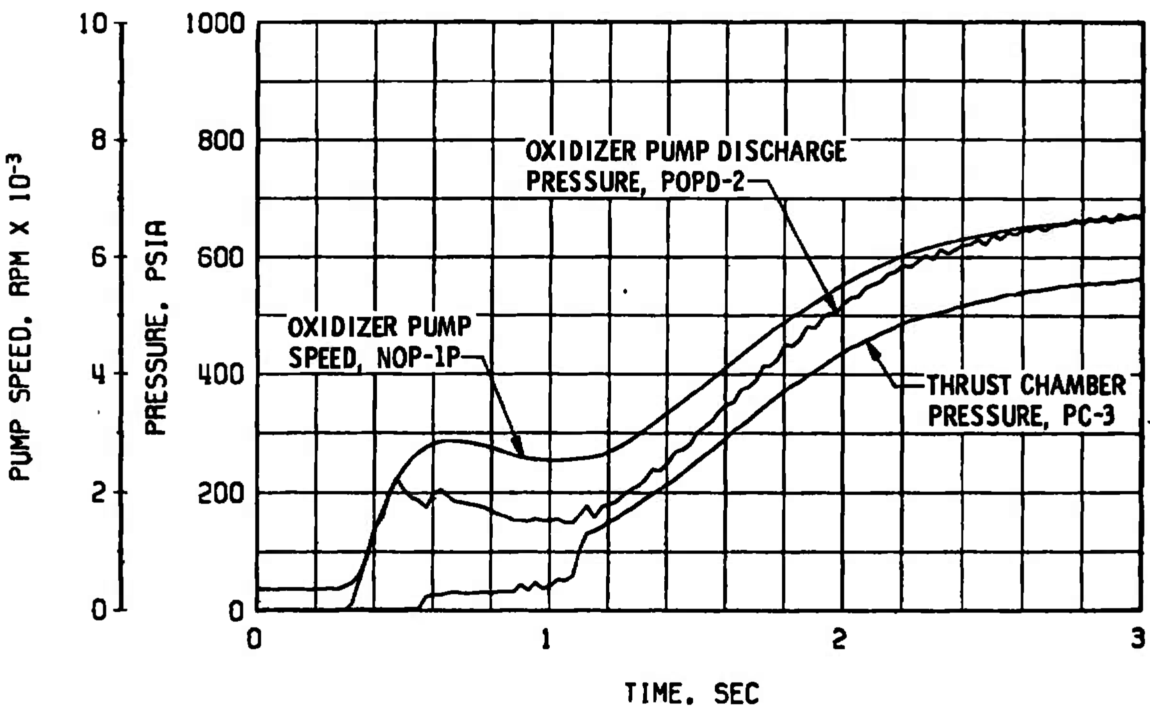



e. Thrust Chamber Conditioning

Fig. 11 Concluded

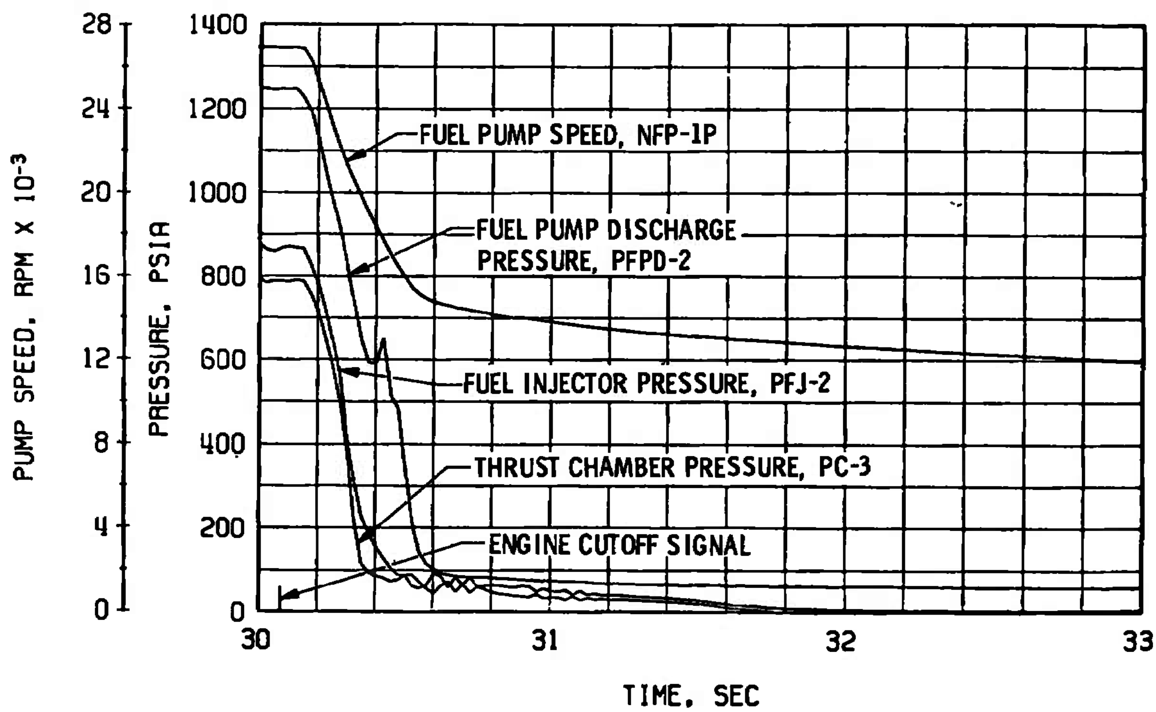



a. Start Transient, Thrust Chamber Fuel System

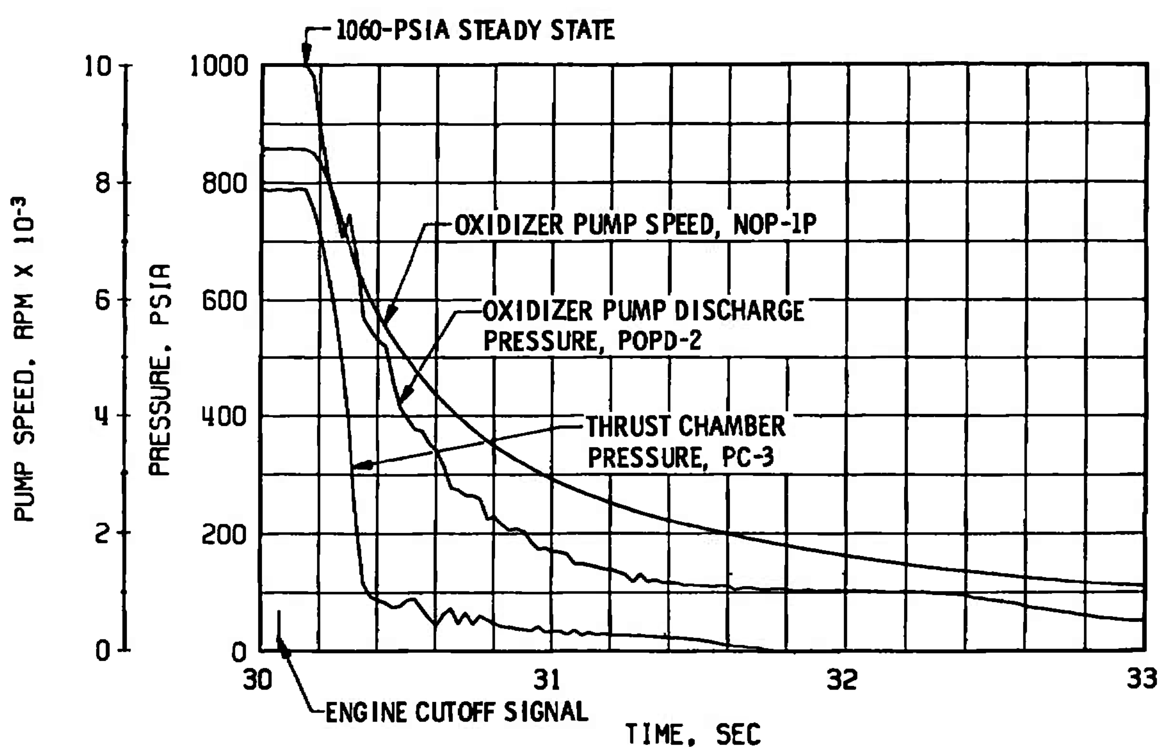



b. Start Transient, Thrust Chamber Oxidizer System

Fig. 12 Engine Transient Operation, Firing 04C

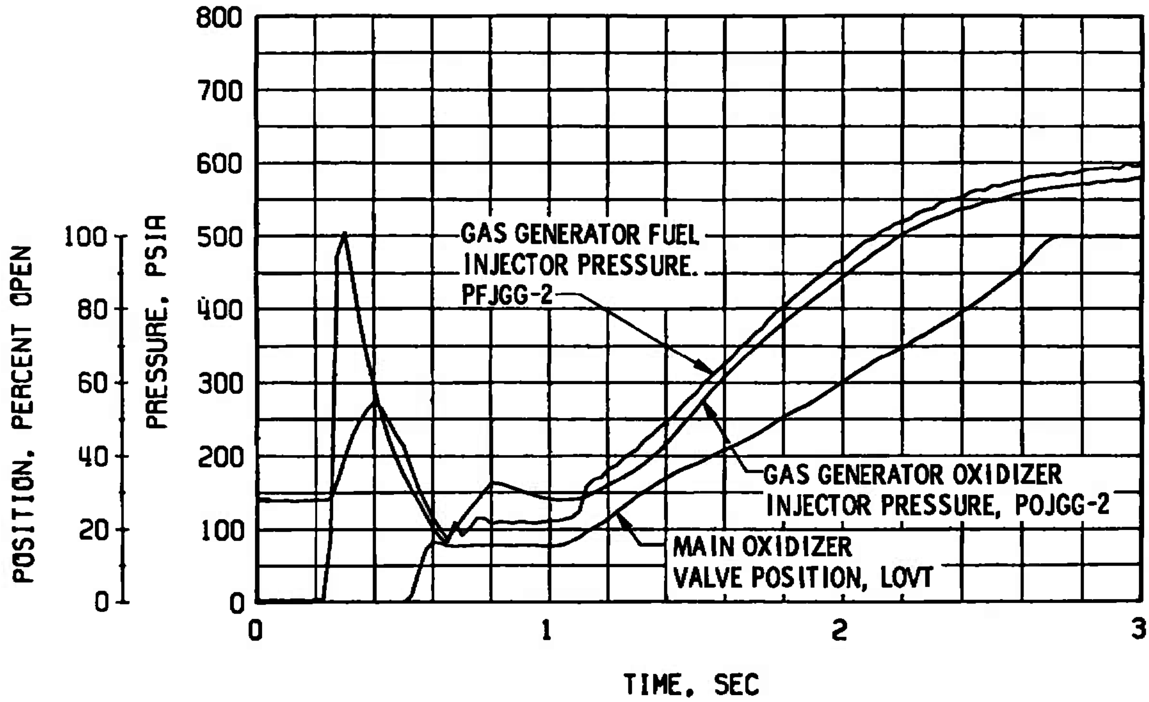


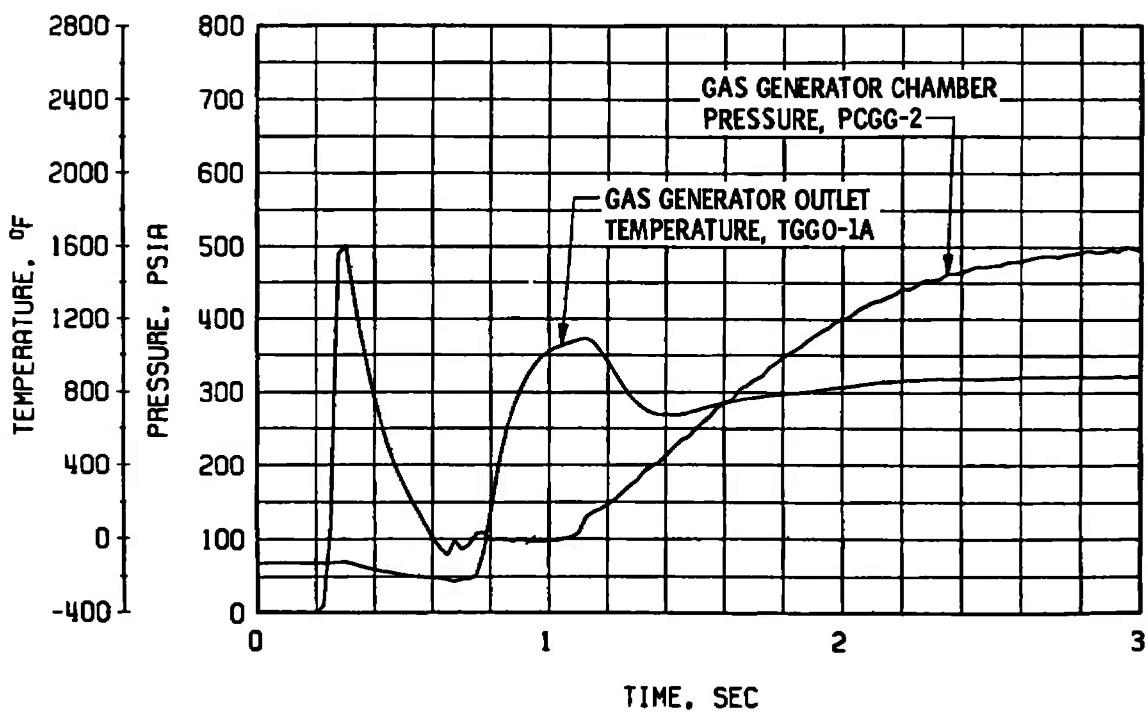

c. Shutdown Transient, Thrust Chamber Fuel System




d. Shutdown Transient, Thrust Chamber Oxidizer System

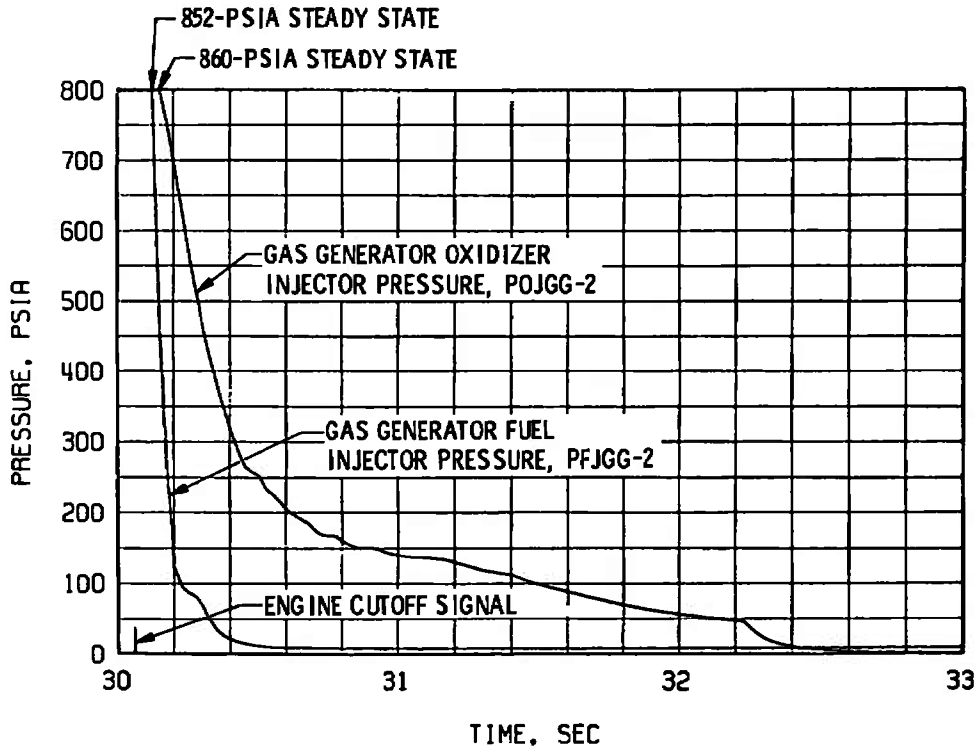
Fig. 12 Continued

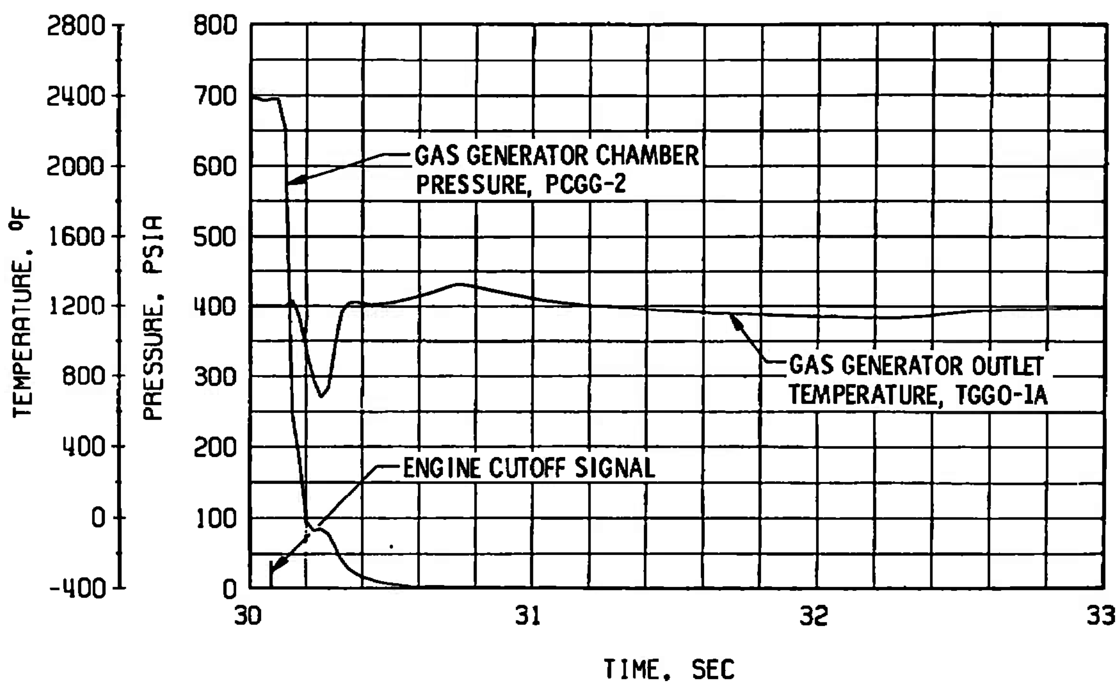



e. Start Transient, Gas Generator

Fig. 12 Continued




f. Shutdown Transient, Gas Generator

Fig. 12 Concluded

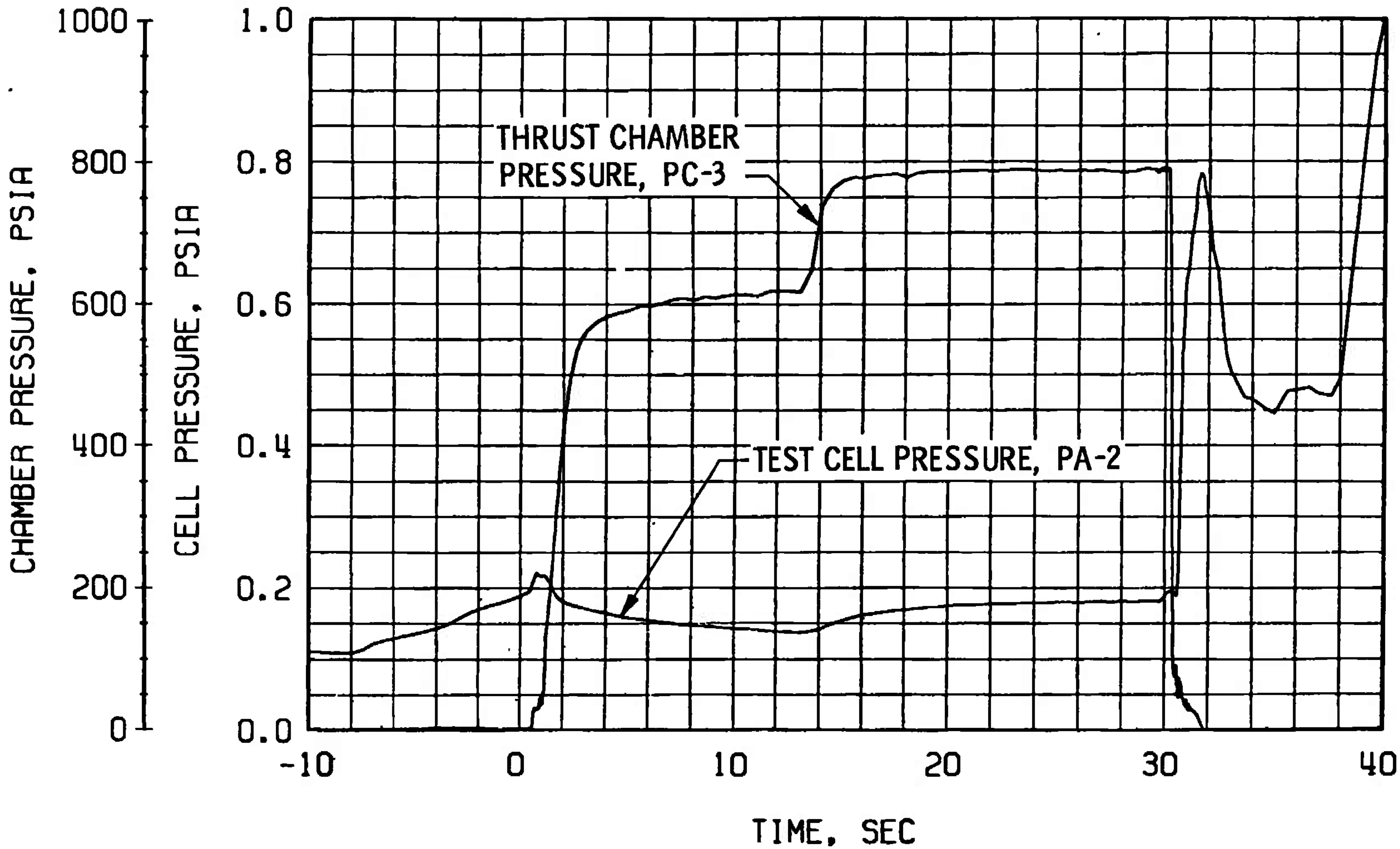
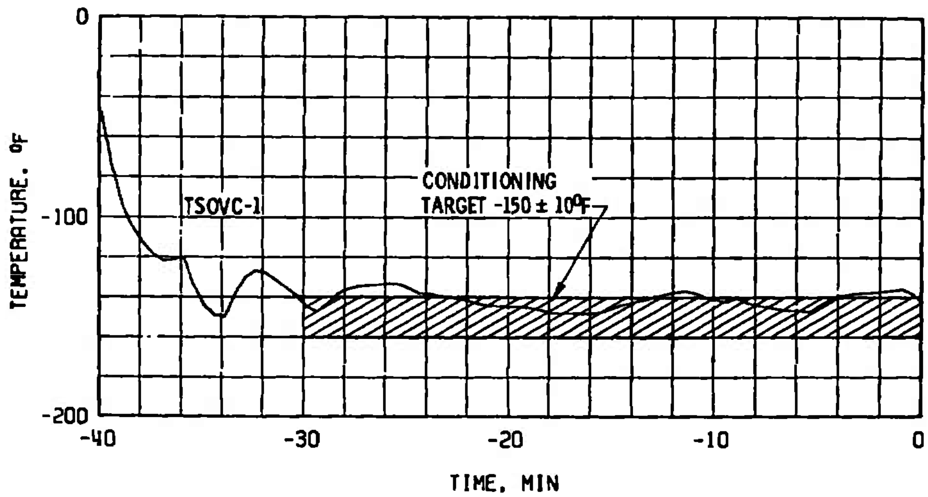
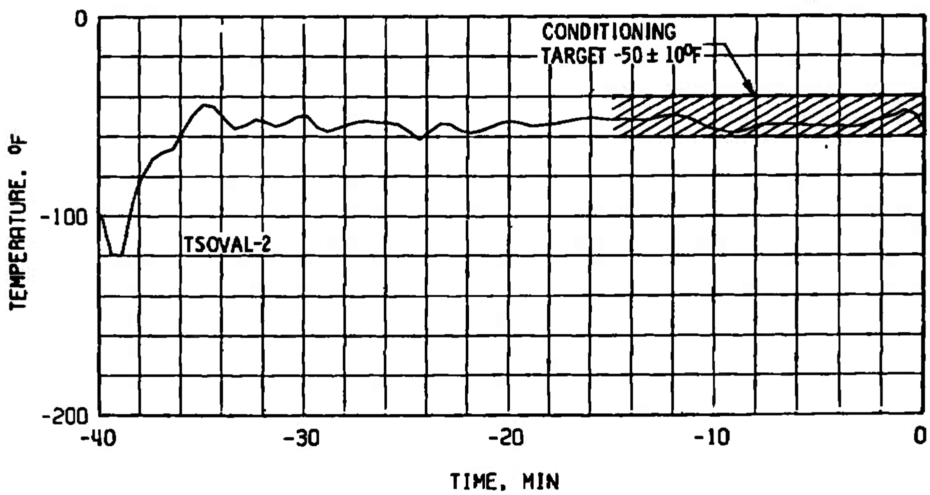


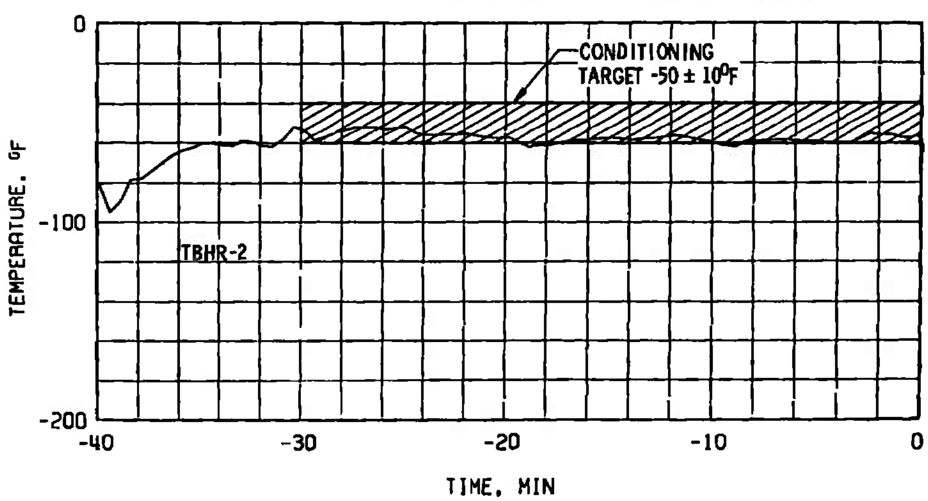

Fig. 13 Engine Ambient and Combustion Chamber Pressures, Firing 04C




a. Main Oxidizer Valve Second-Stage Actuator Conditioning

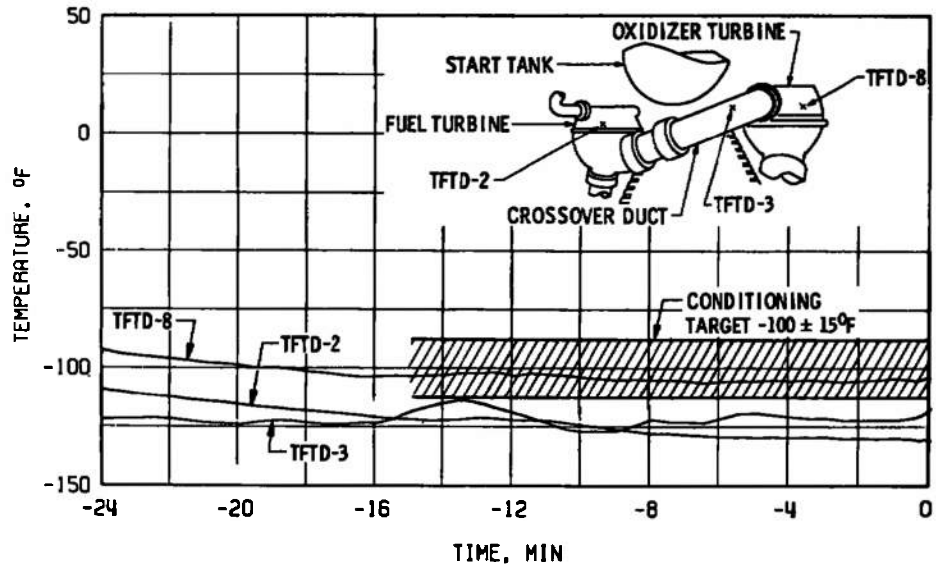



b. Main Oxidizer Valve Closing Control Line Conditioning

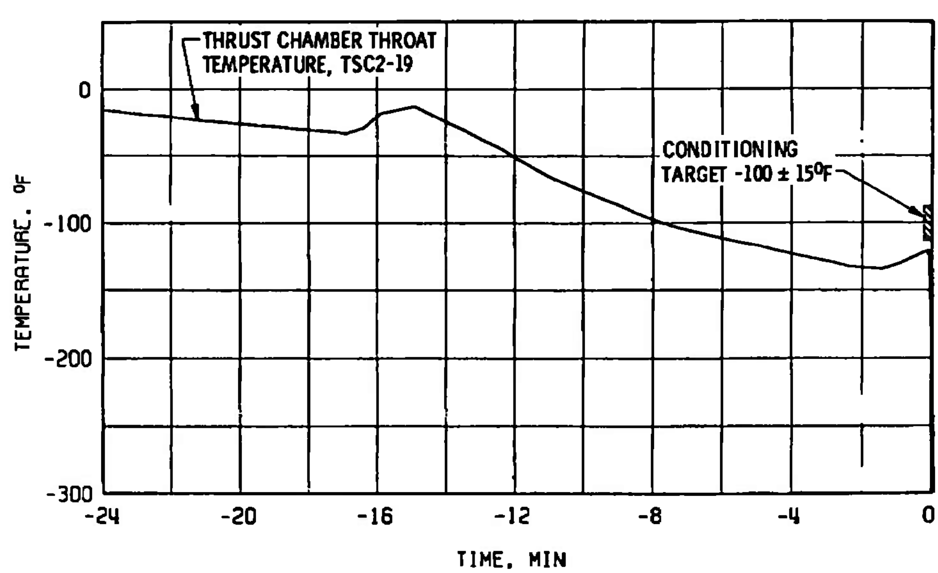



c. Pneumatic Control Package Conditioning

Fig. 14 Thermal Conditioning History of Engine Components, Firing 04C




d. Crossover Duct Conditioning




e. Thrust Chamber Conditioning

Fig. 14 Concluded

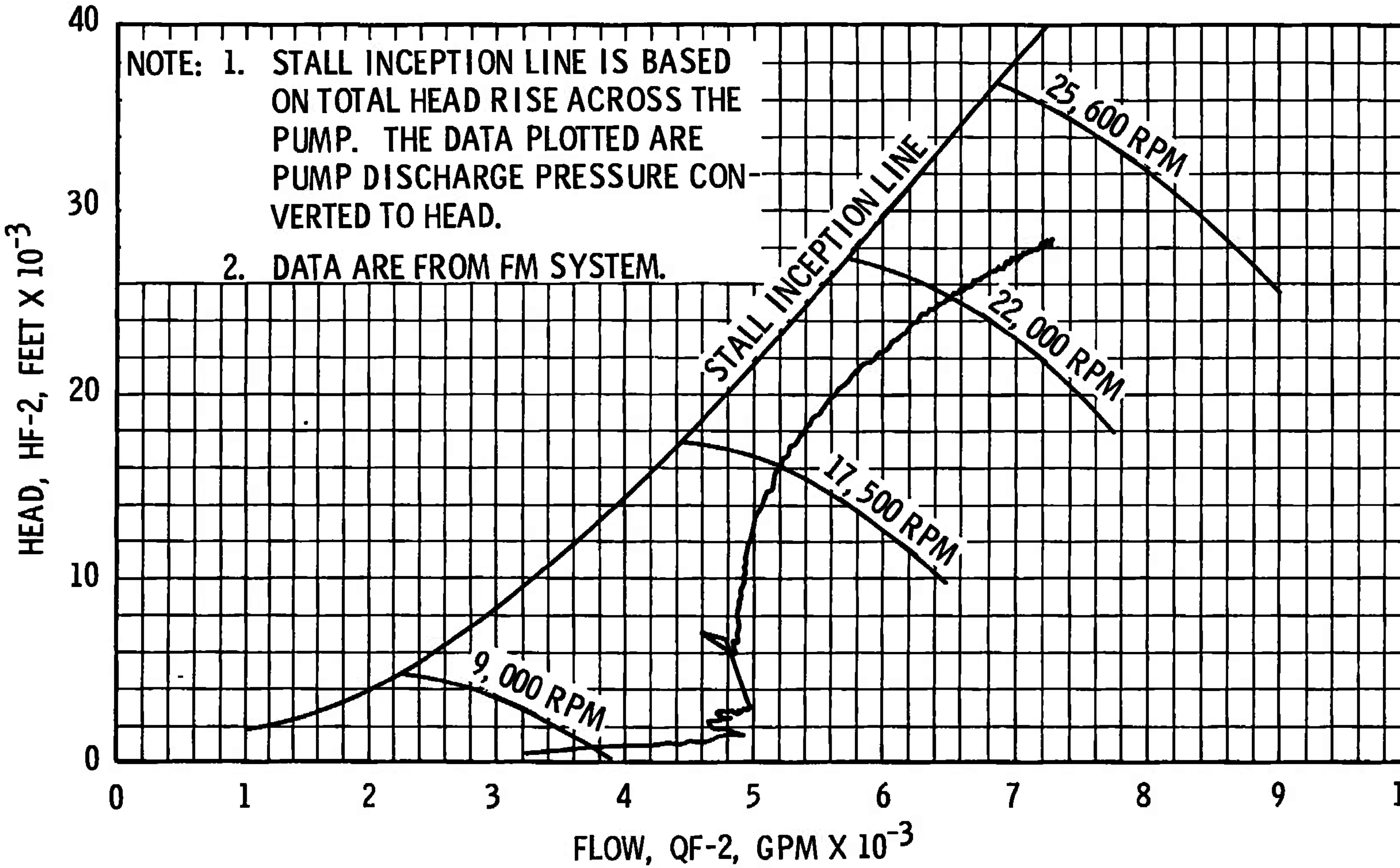



Fig. 15 Fuel Pump Start Transient Performance, Firing 04C

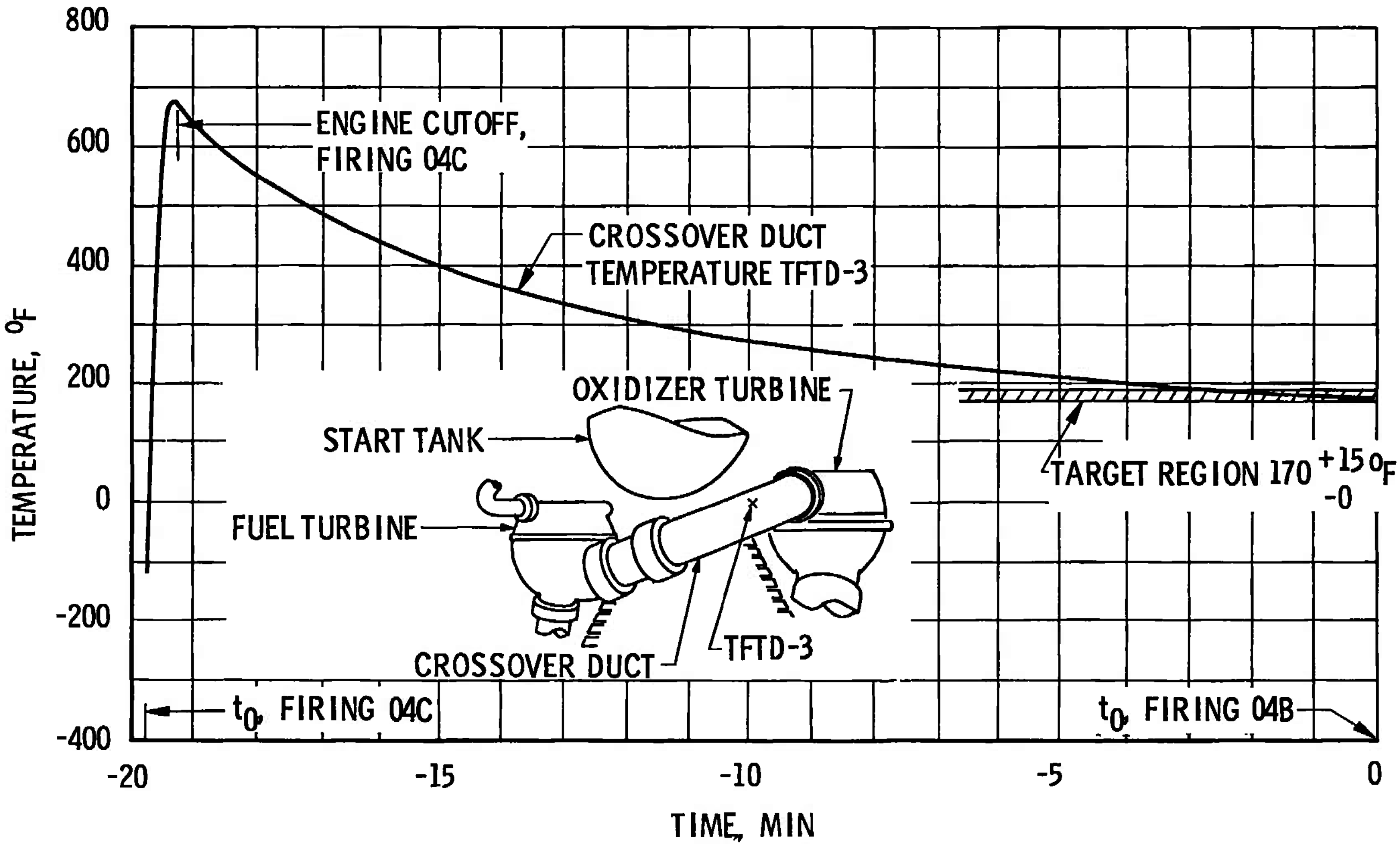
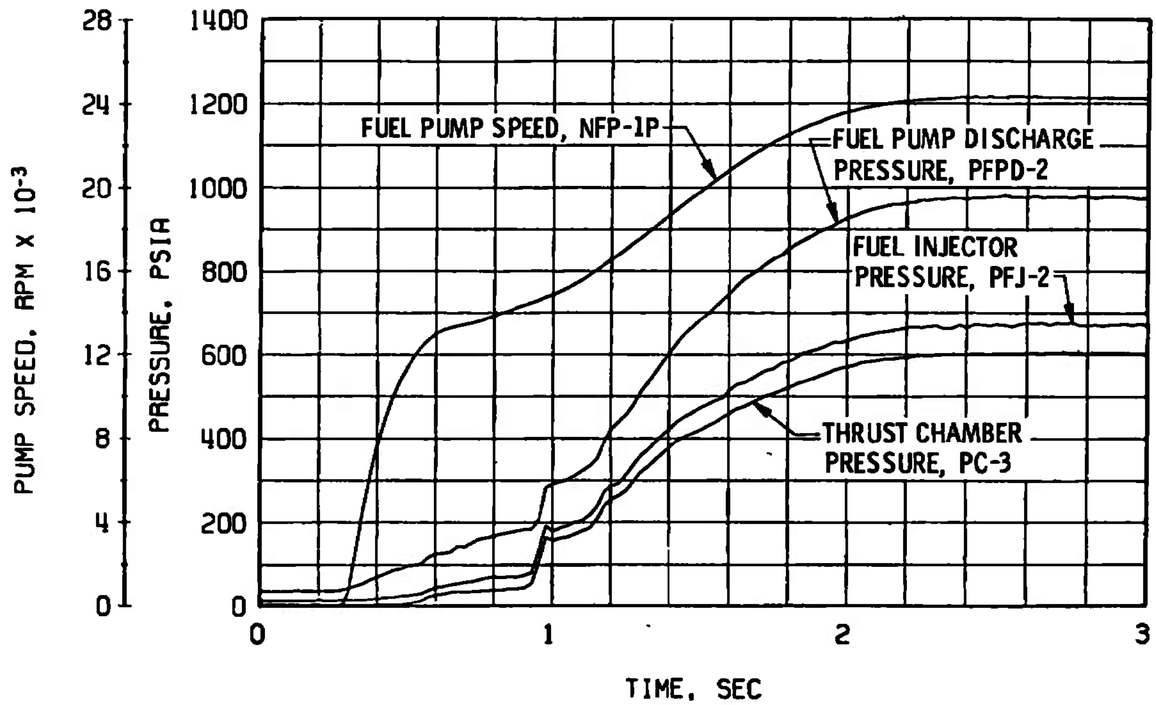
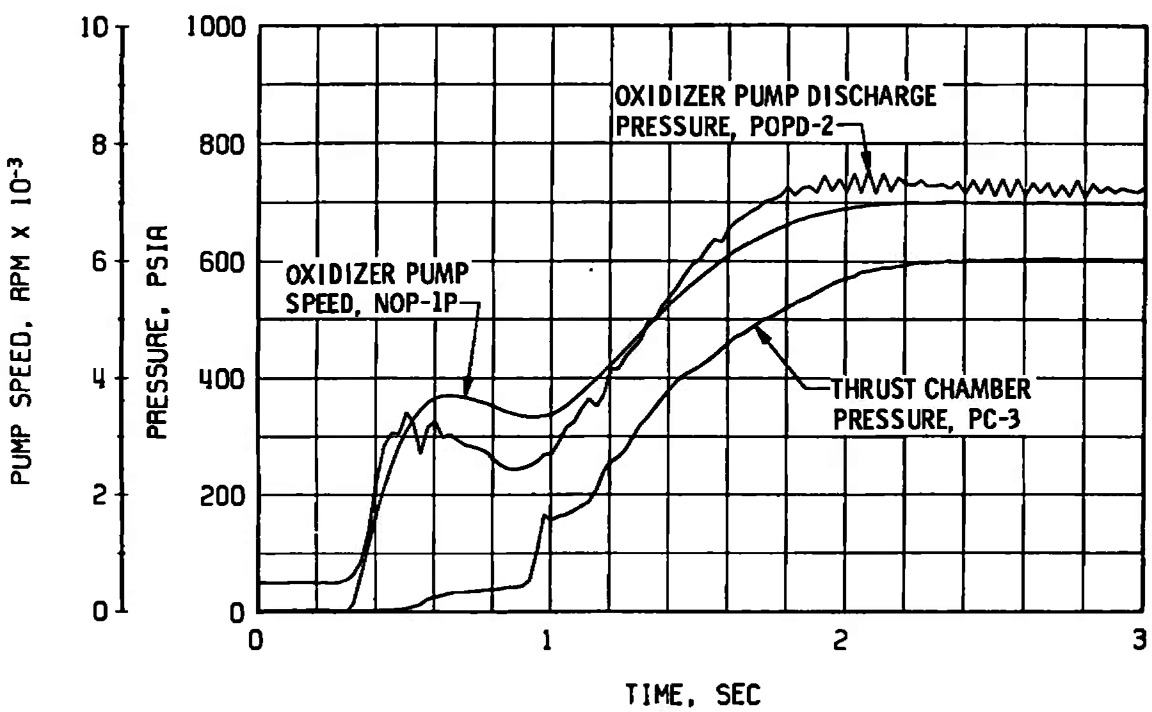



Fig. 16 Crossover Duct Cooldown Rate between Firings 04C and 04B

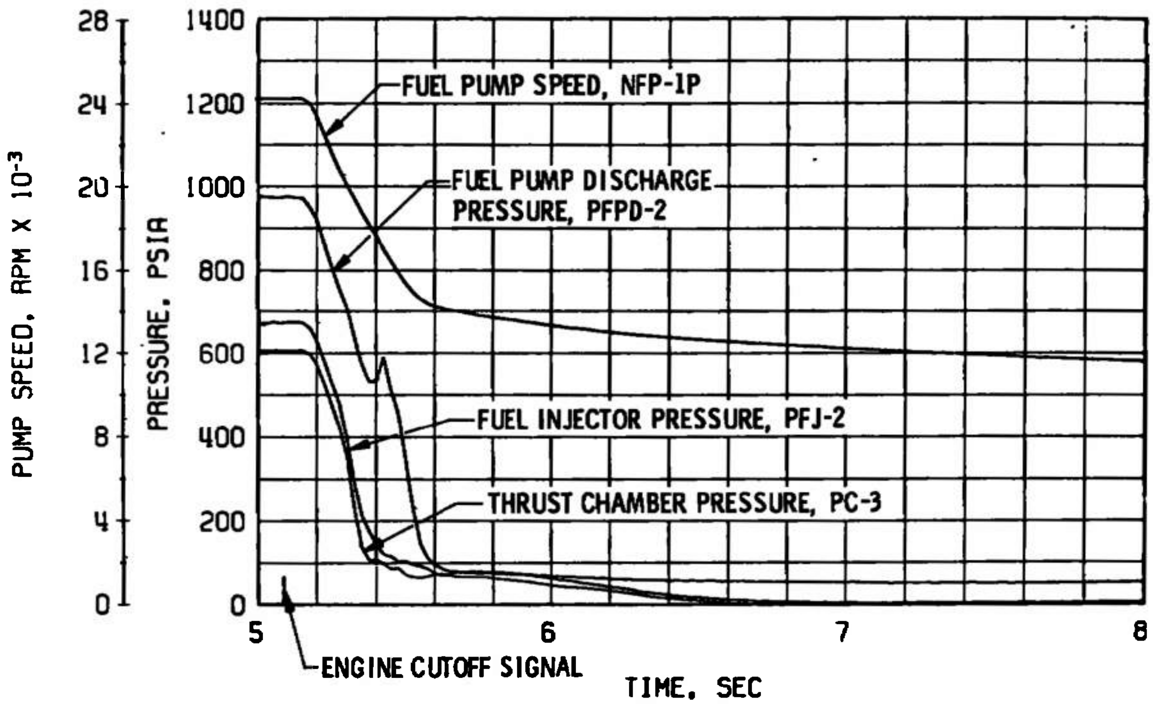



a. Start Transient, Thrust Chamber Fuel System

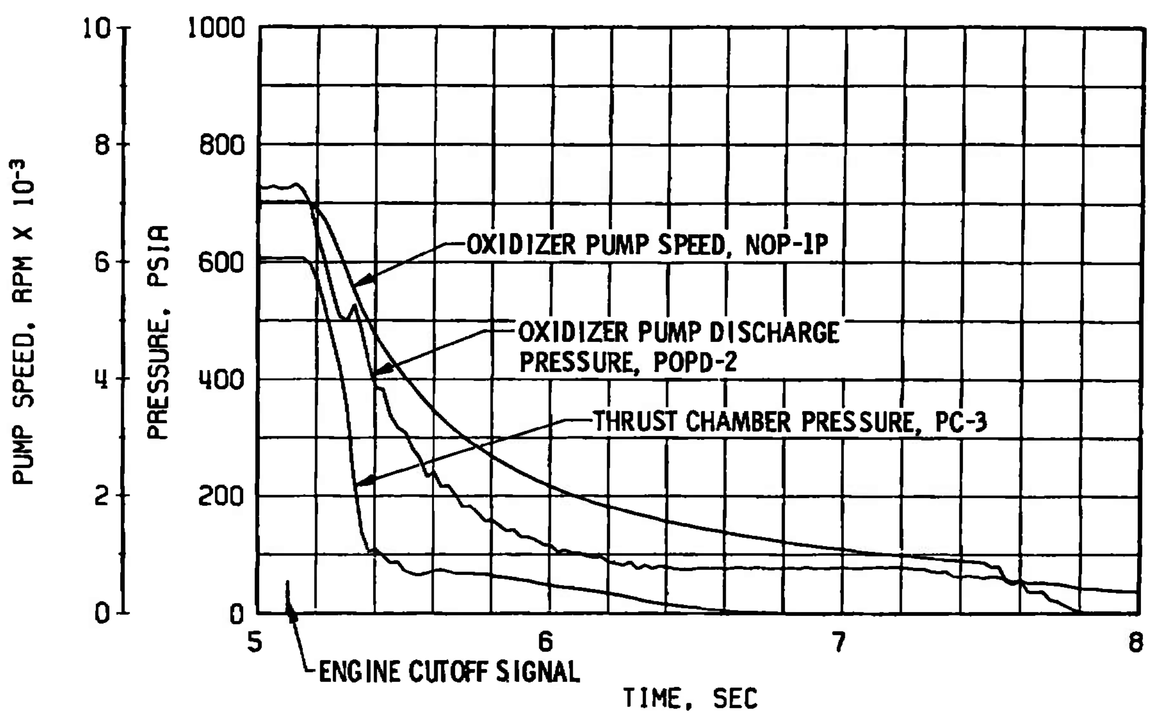



b. Start Transient, Thrust Chamber Oxidizer System

Fig. 17 Engine Transient Operation, Firing 04B

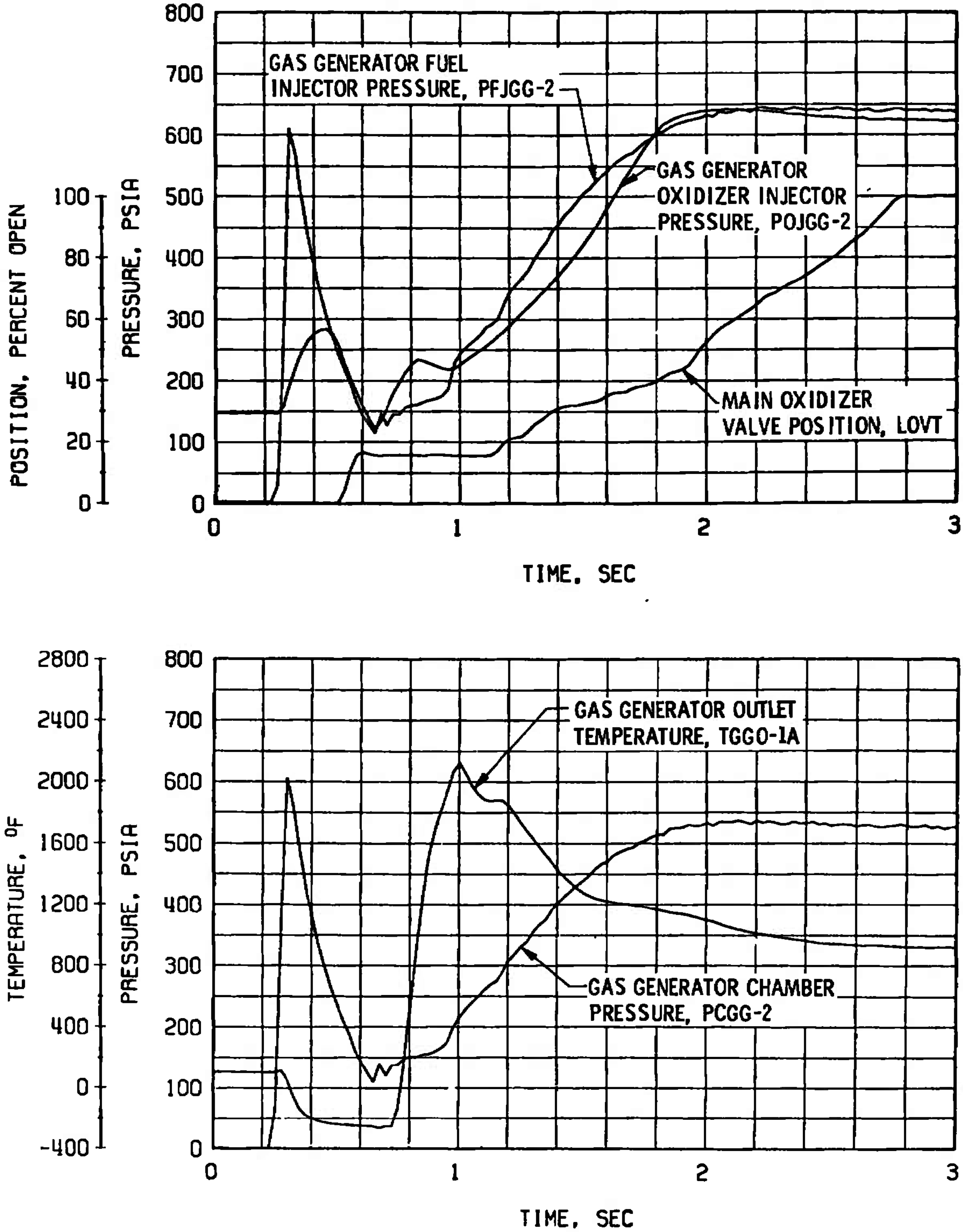



c. Shutdown Transient, Thrust Chamber Fuel System



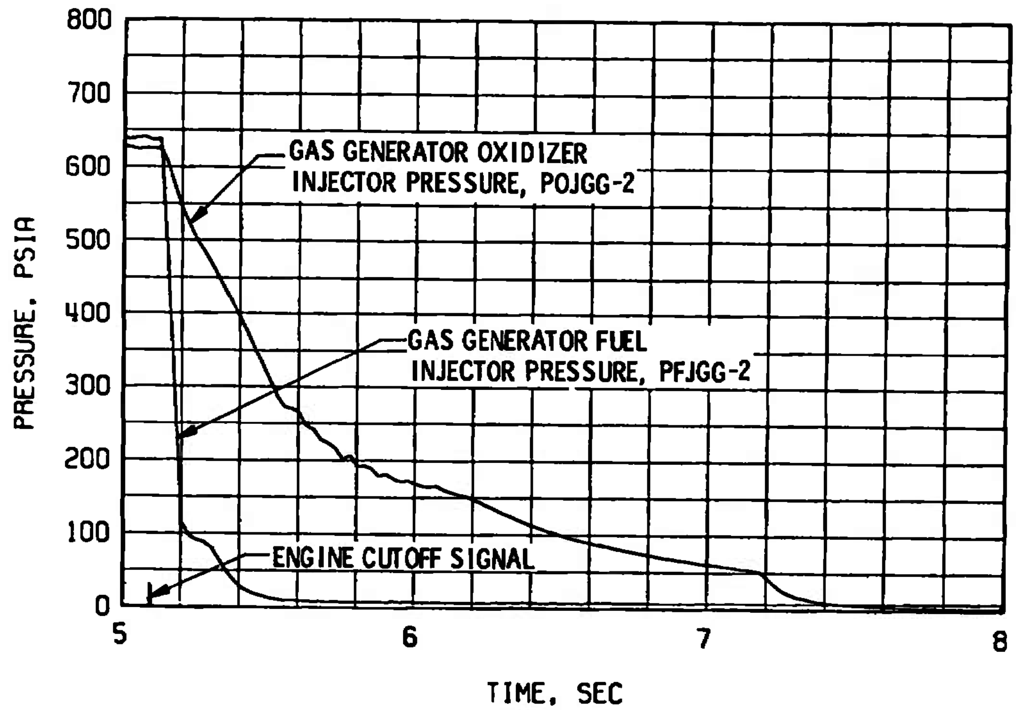

d. Shutdown Transient, Thrust Chamber Oxidizer System

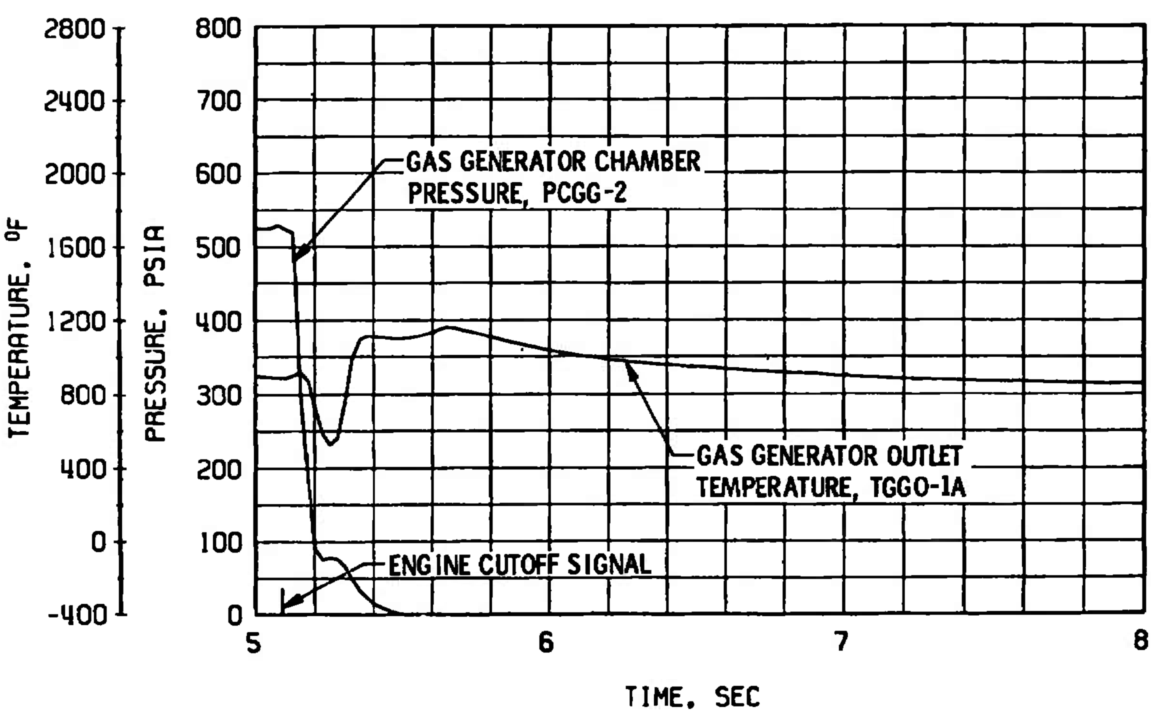
Fig. 17 Continued




e. Start Transient, Gas Generator

Fig. 17 Continued




f. Shutdown Transient, Gas Generator

Fig. 17 Concluded

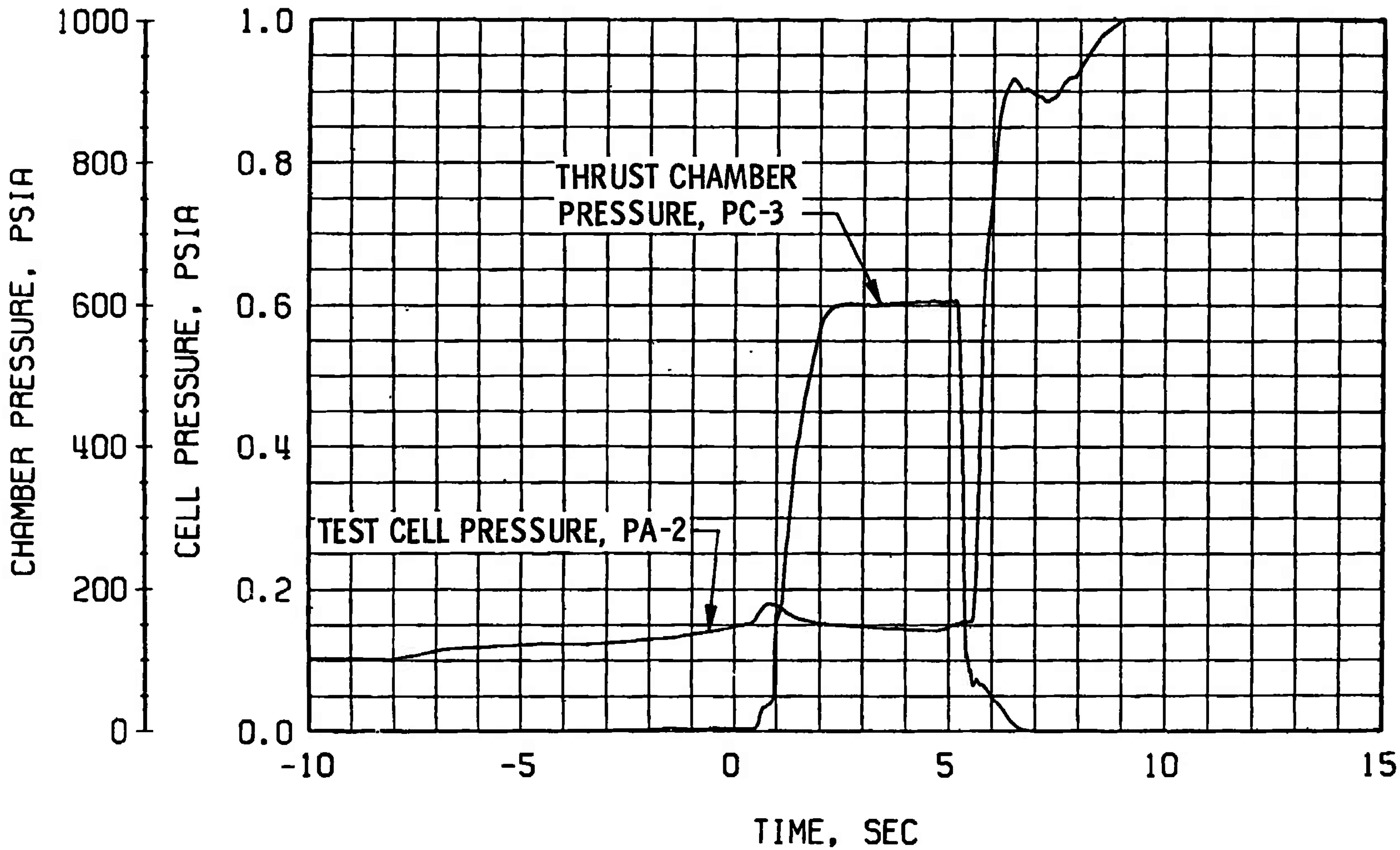
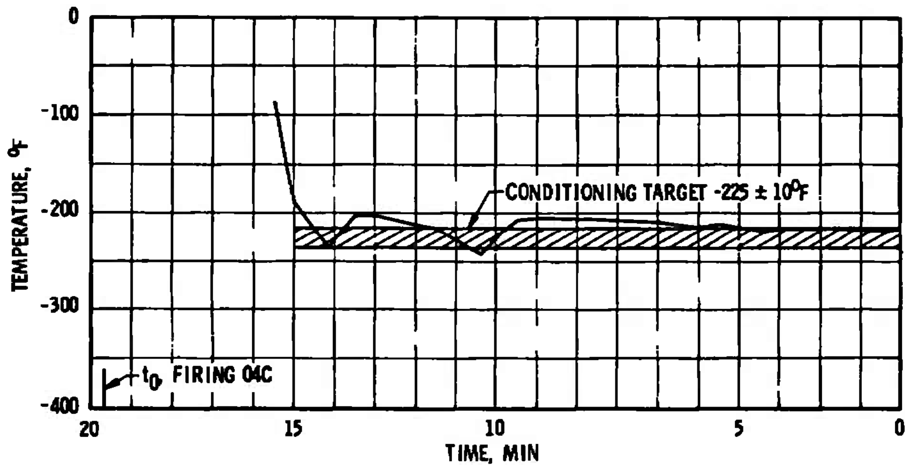
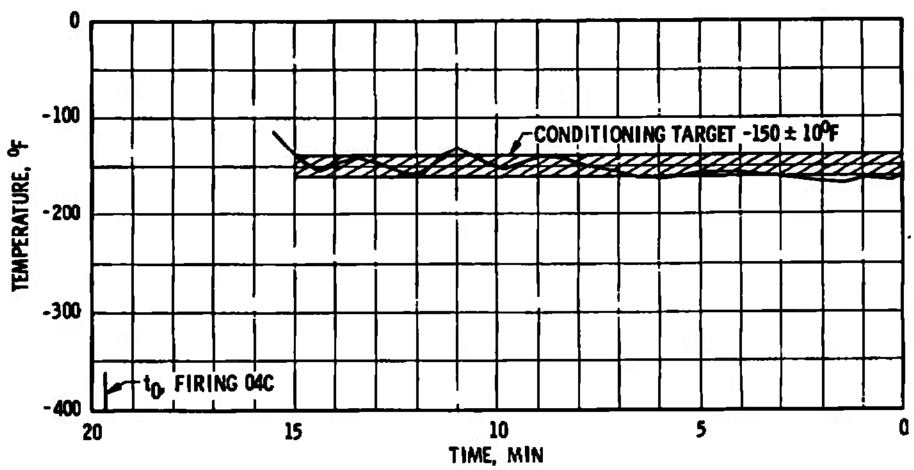


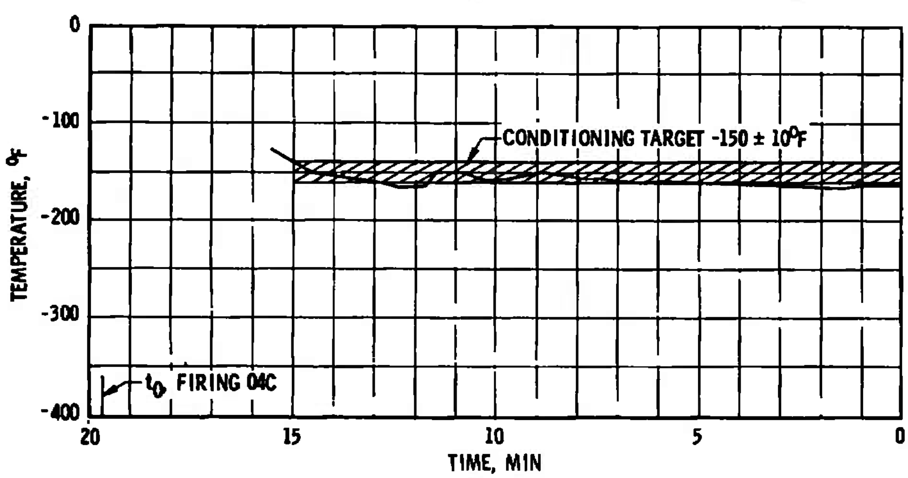

Fig. 18 Engine Ambient and Combustion Chamber Pressures, Firing 04B




a. Main Oxidizer Valve Second-Stage Actuator Conditioning




b. Main Oxidizer Valve Closing Control Line Conditioning




c. Pneumatic Control Package Conditioning

Fig. 19 Thermal Conditioning History of Engine Components, Firing 04B

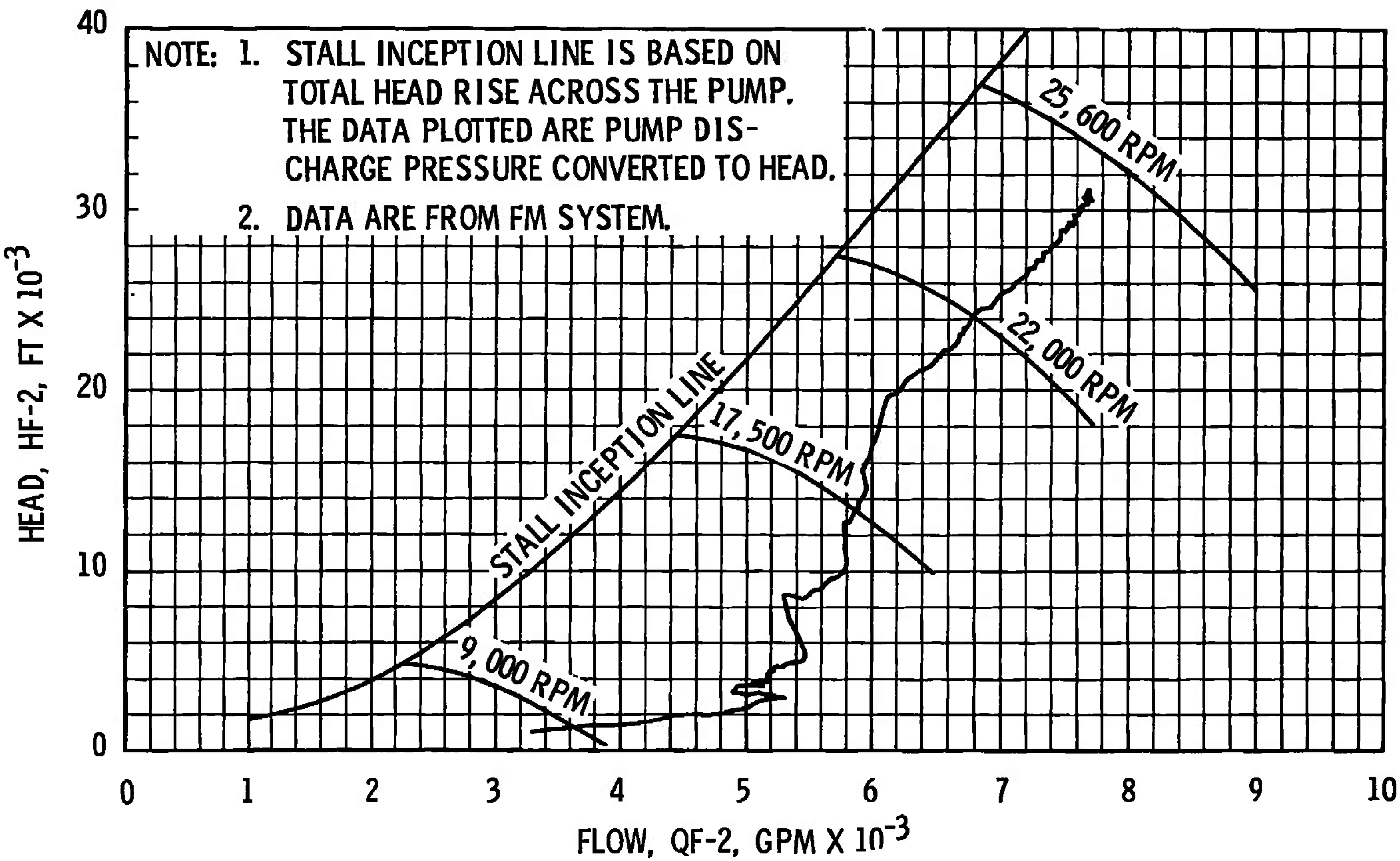
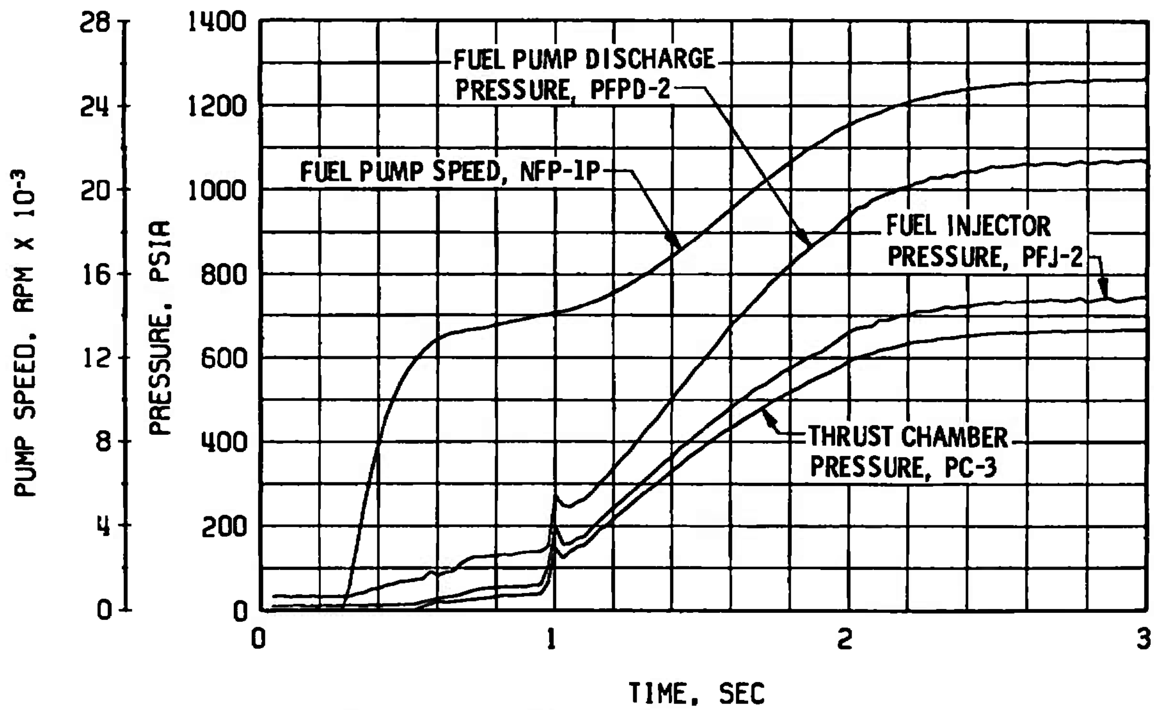
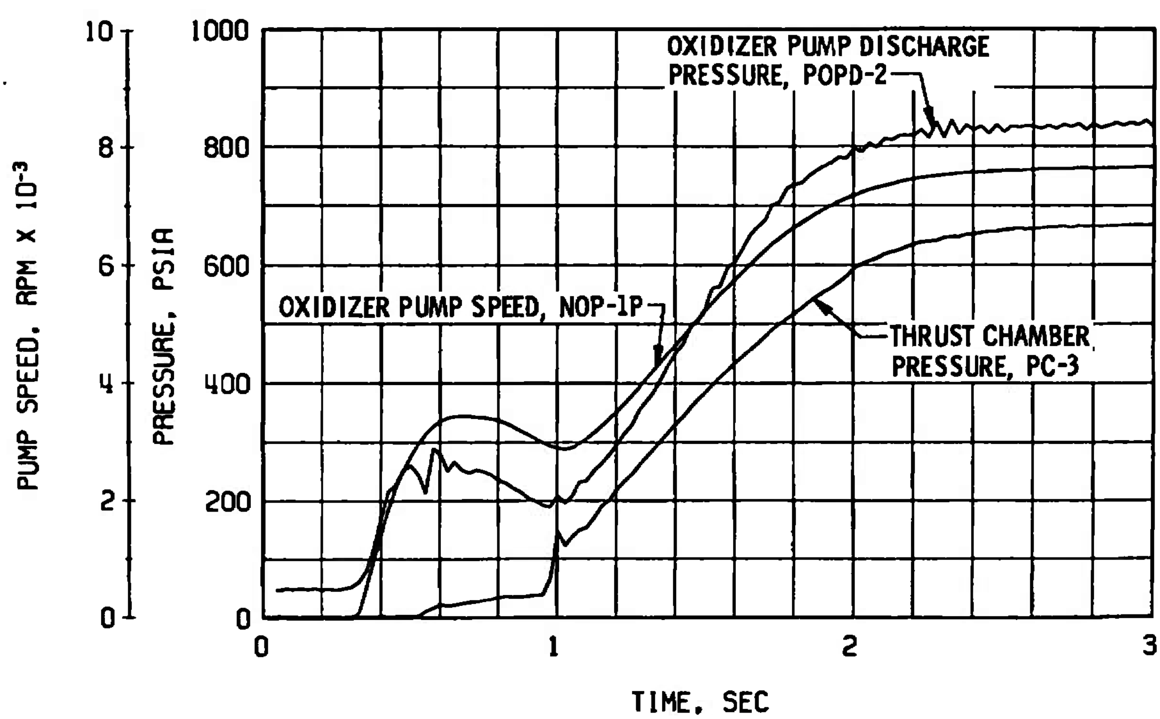



Fig. 20 Fuel Pump Start Transient Performance, Firing 04B

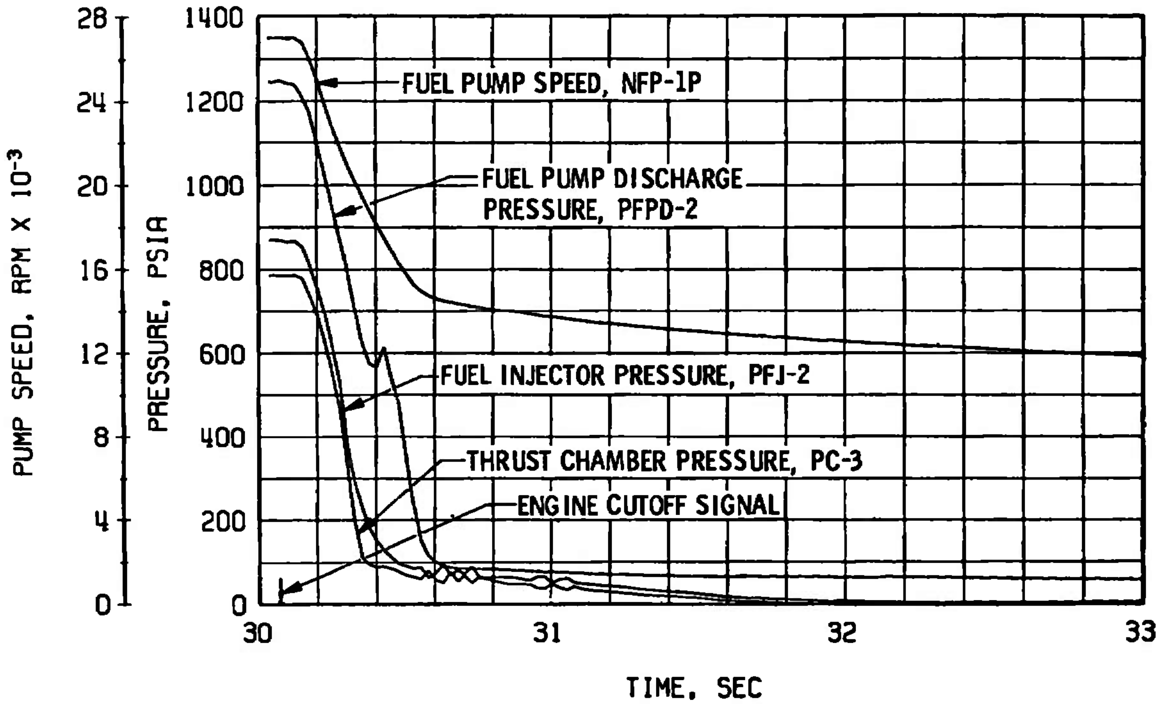



a. Start Transient, Thrust Chamber Fuel System

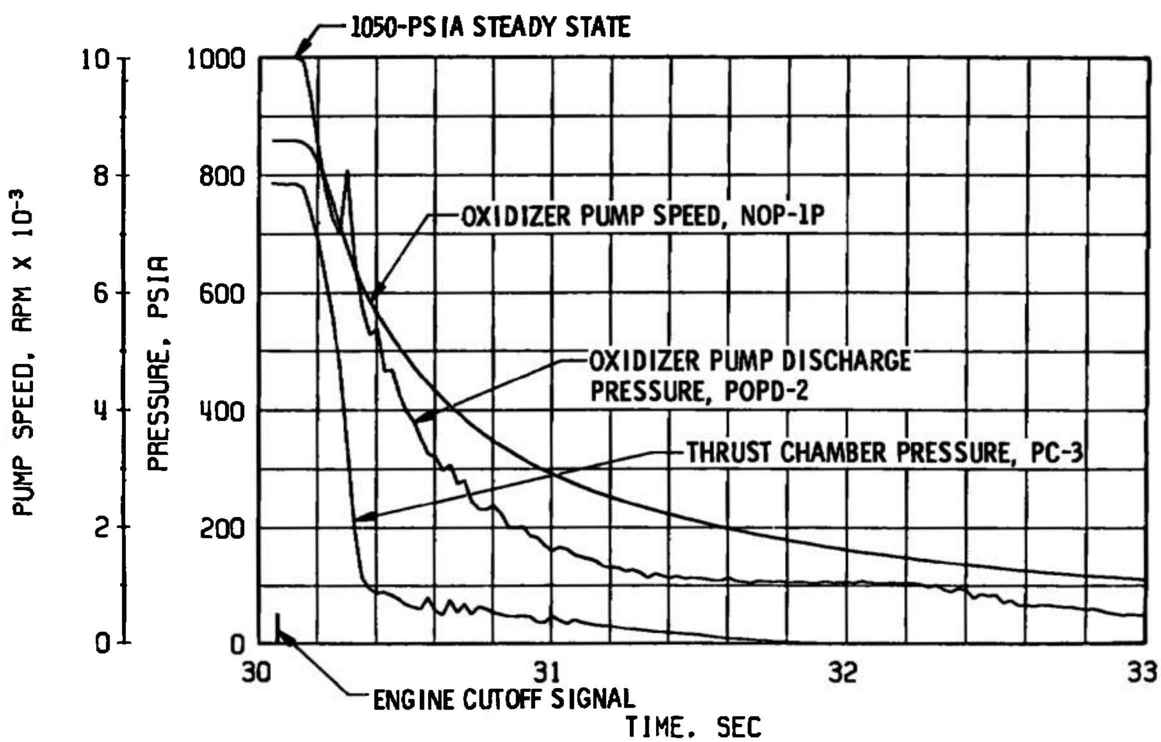



b. Start Transient, Thrust Chamber Oxidizer System

Fig. 21 Engine Transient Operation, Firing 04E

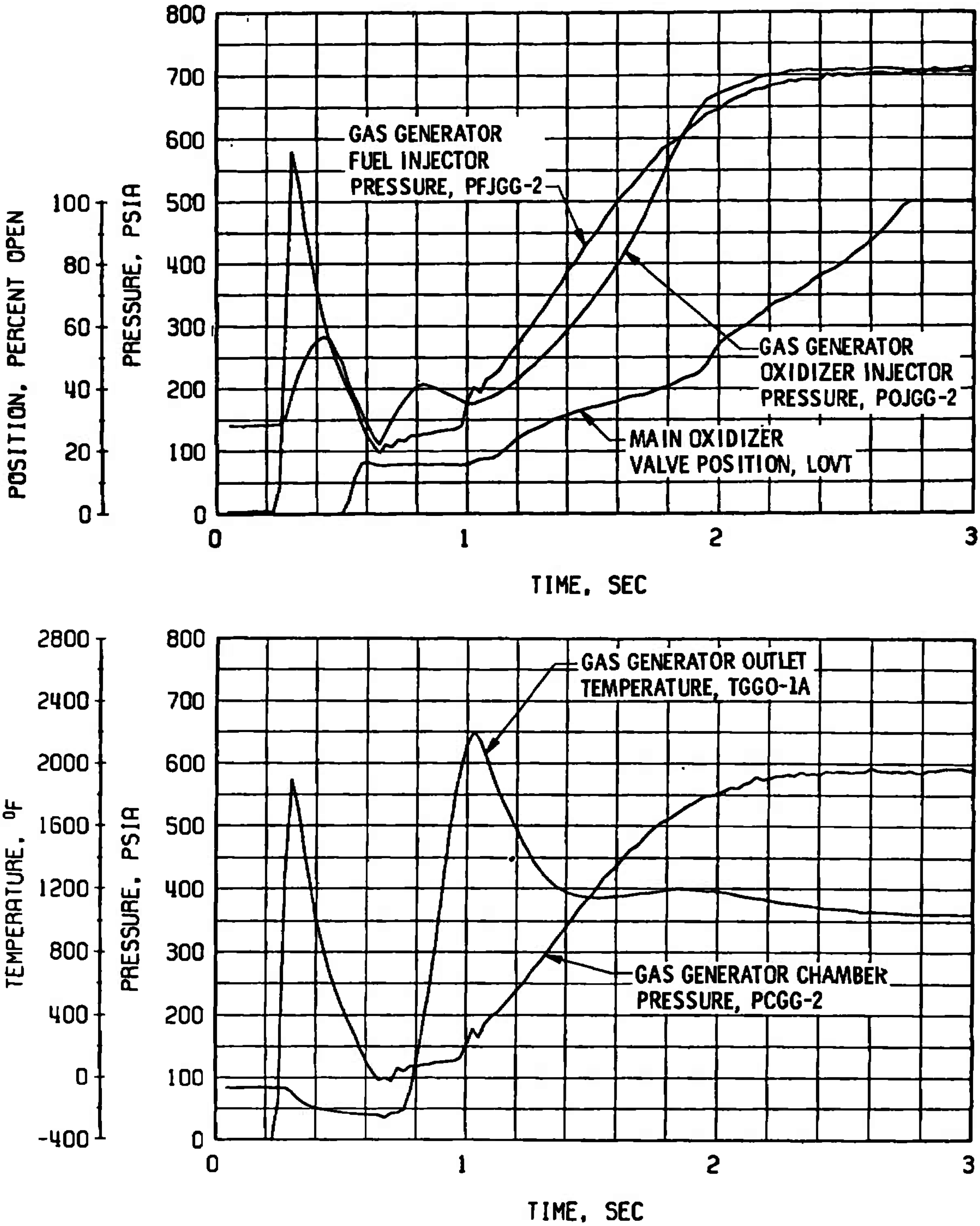



c. Shutdown Transient, Thrust Chamber Fuel System



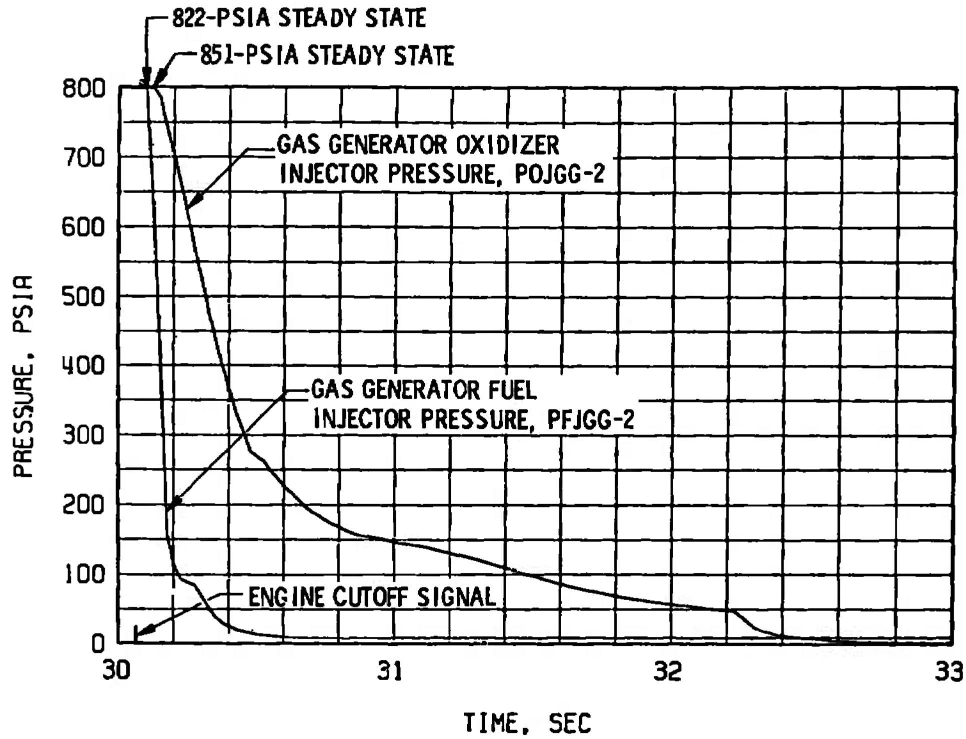

d. Shutdown Transient, Thrust Chamber Oxidizer System

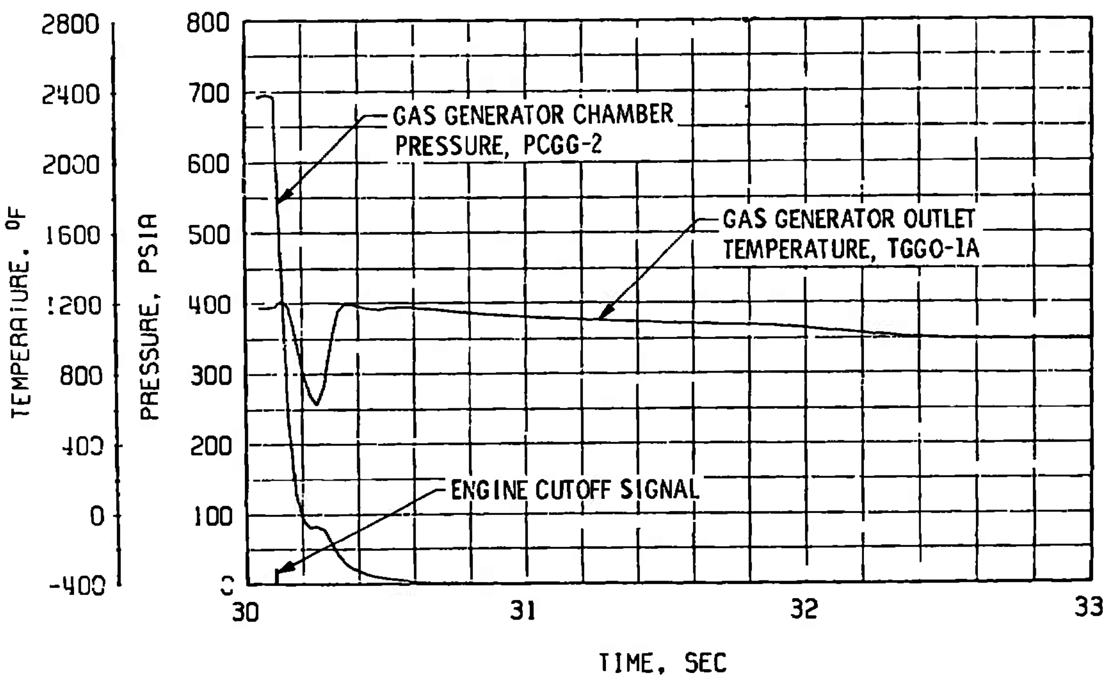
Fig. 21 Continued




e. Start Transient, Gas Generator

Fig. 21 Continued




**f. Shutdown Transient, Gas Generator**

**Fig. 21 Concluded**

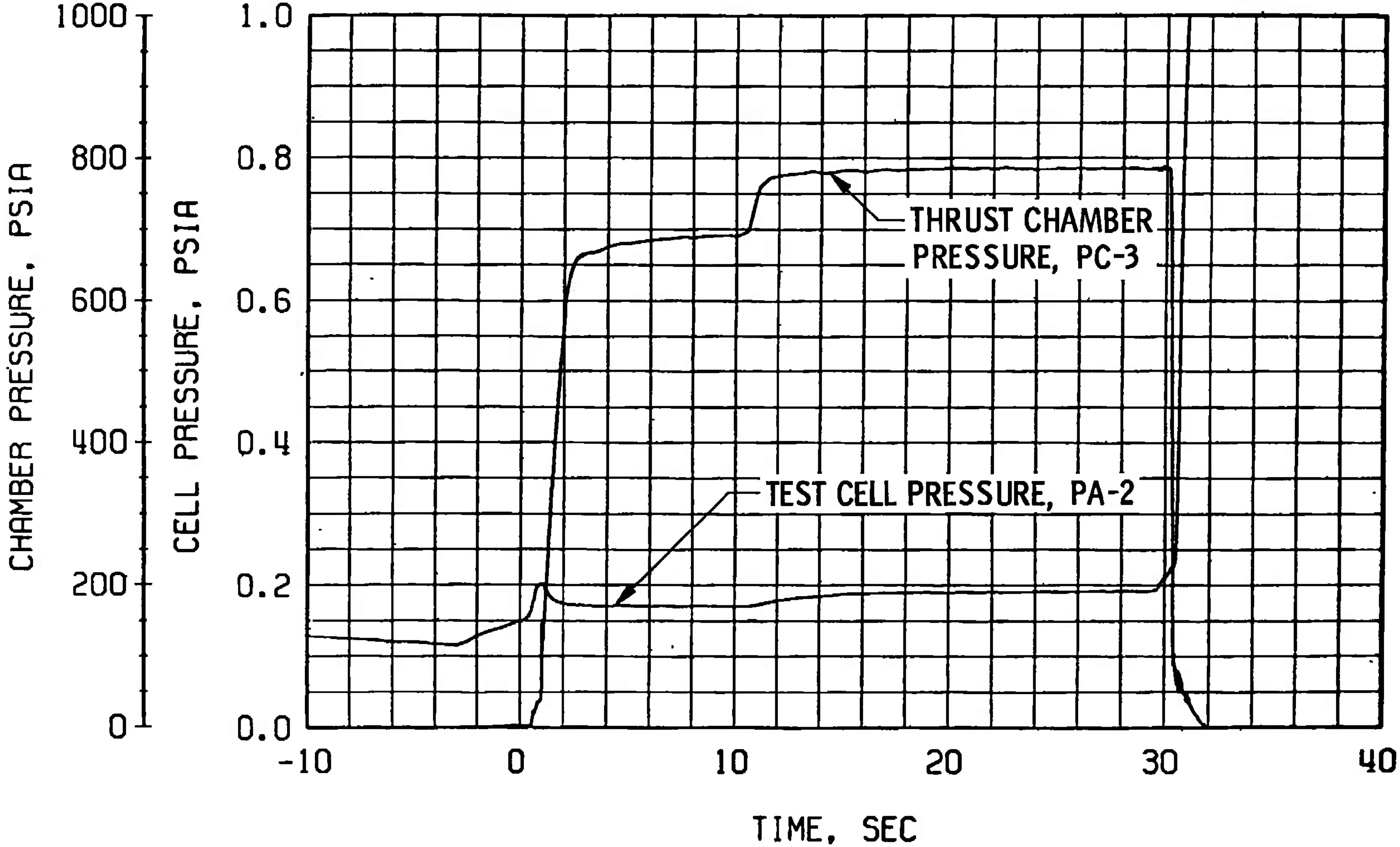
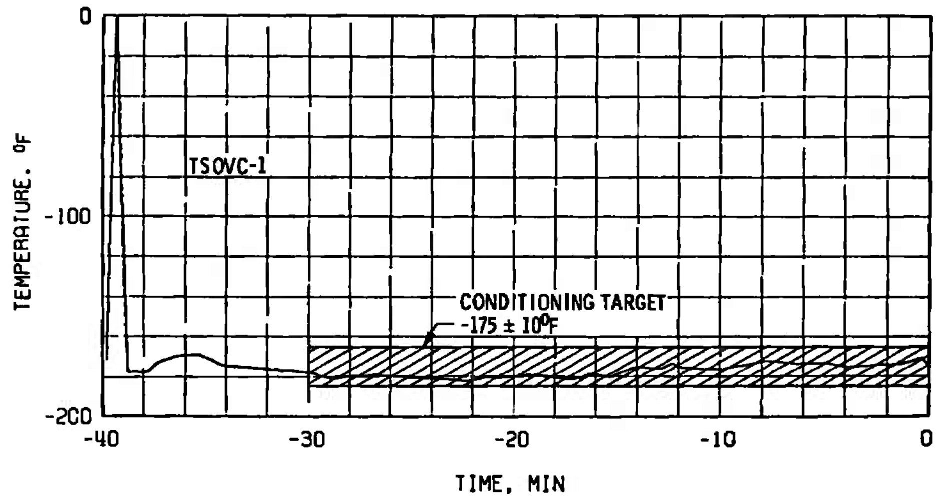
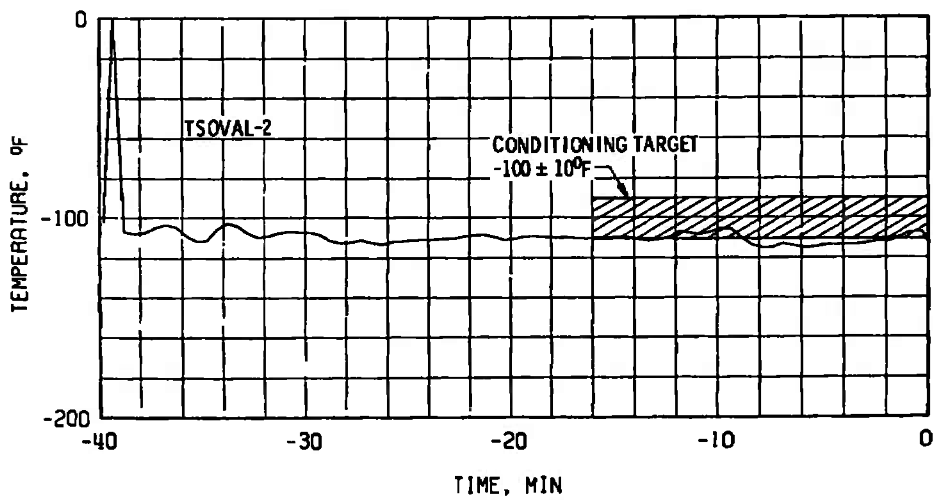


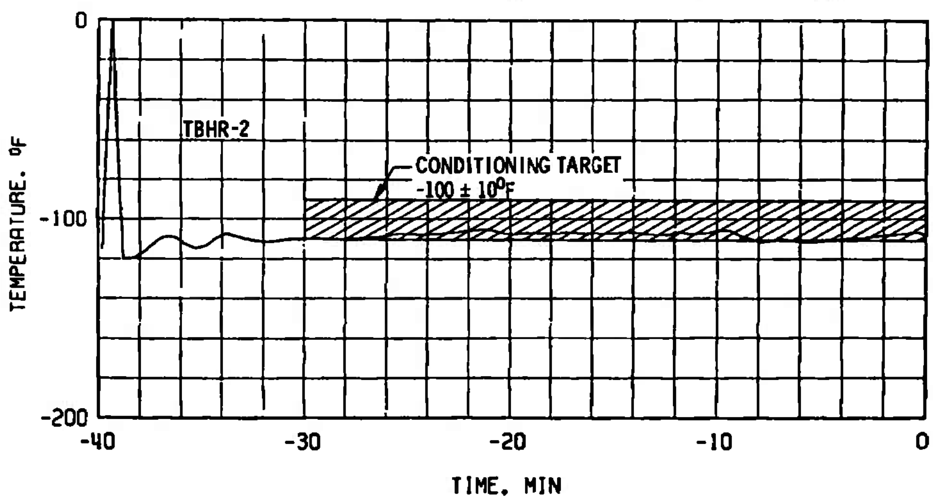

**Fig. 22 Engine Ambient and Combustion Chamber Pressures, Firing 04E**




a. Main Oxidizer Valve Second-Stage Actuator Conditioning

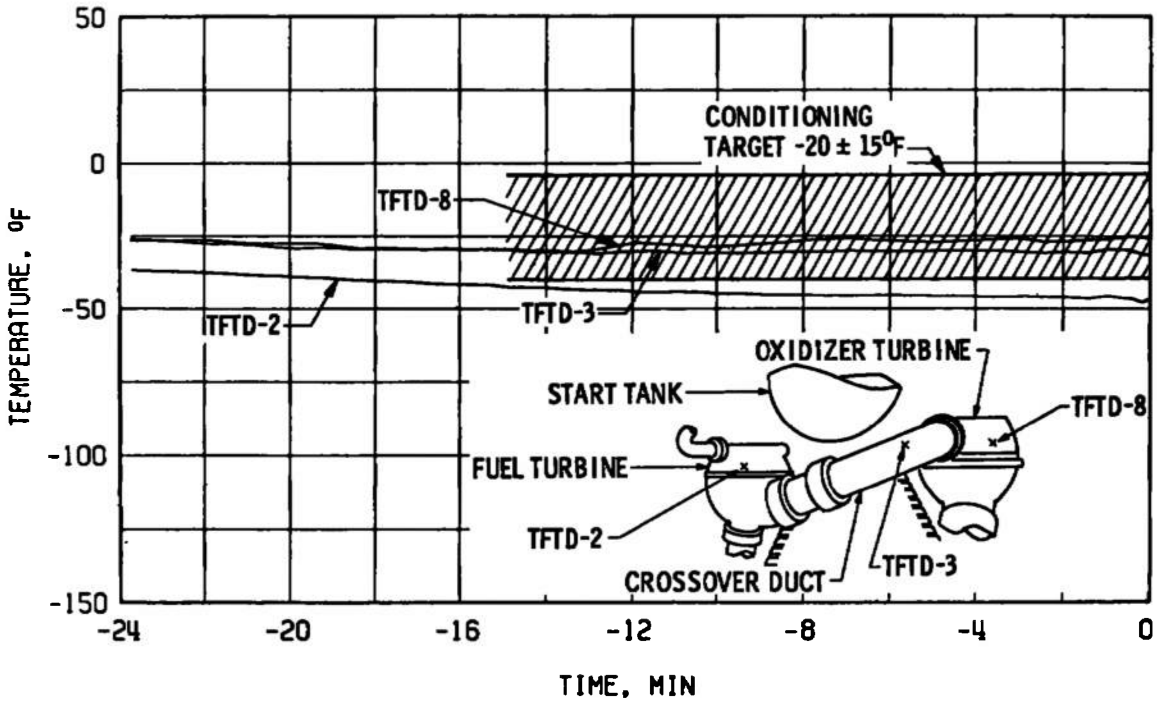



b. Main Oxidizer Valve Closing Control Line Conditioning

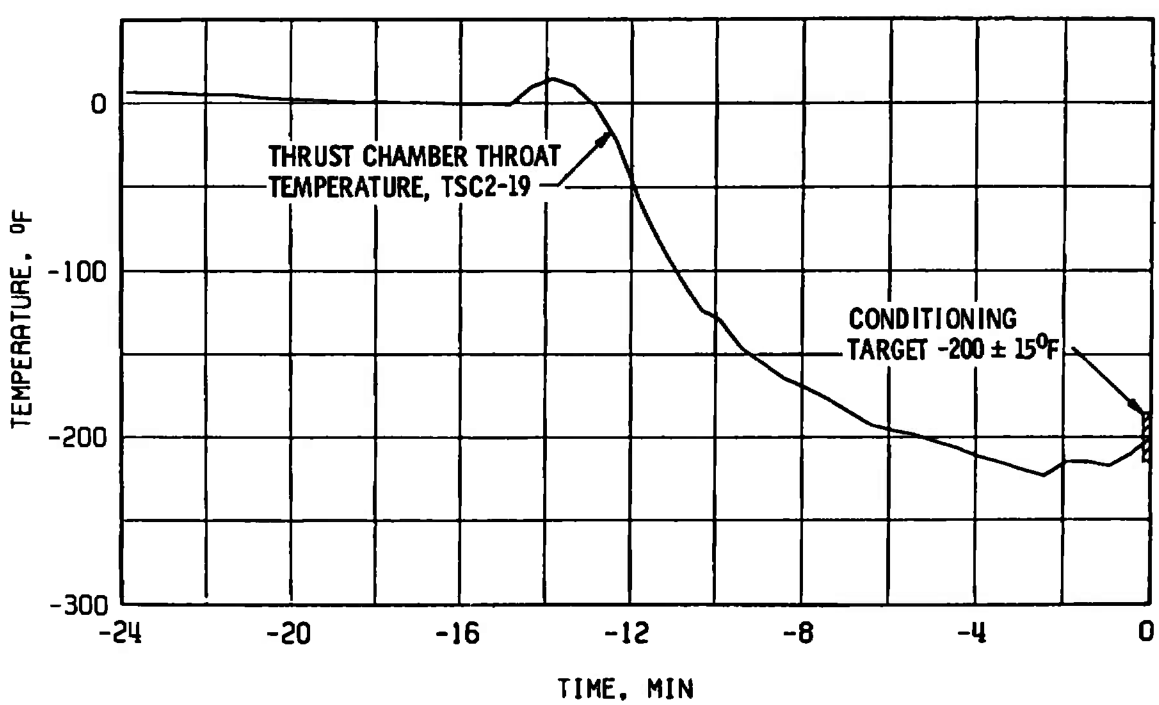



c. Pneumatic Control Package Conditioning

Fig. 23 Thermal Conditioning History of Engine Components, Firing 04E

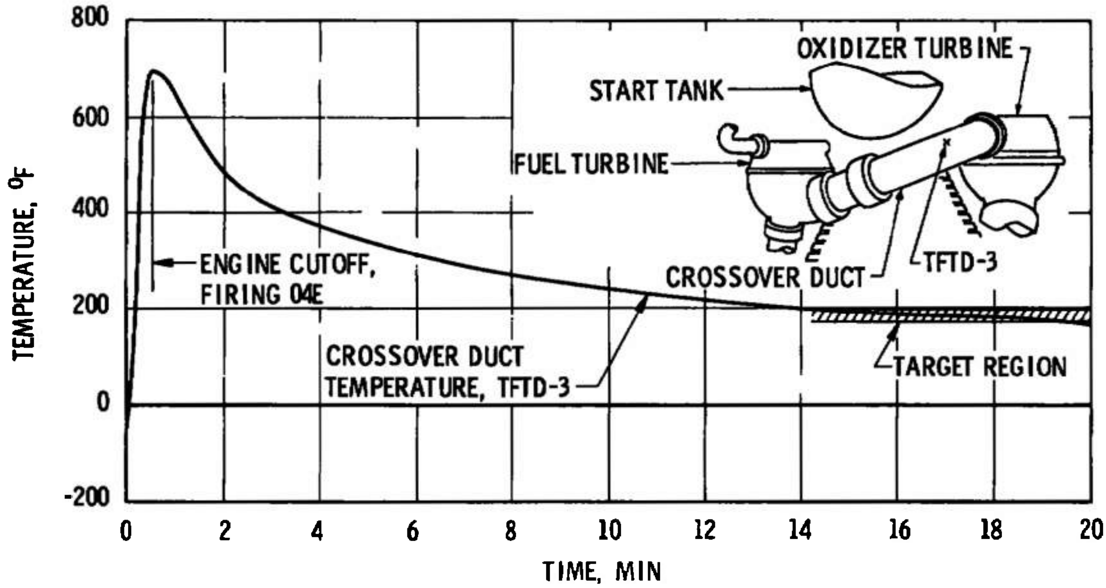



d. Crossover Duct Conditioning

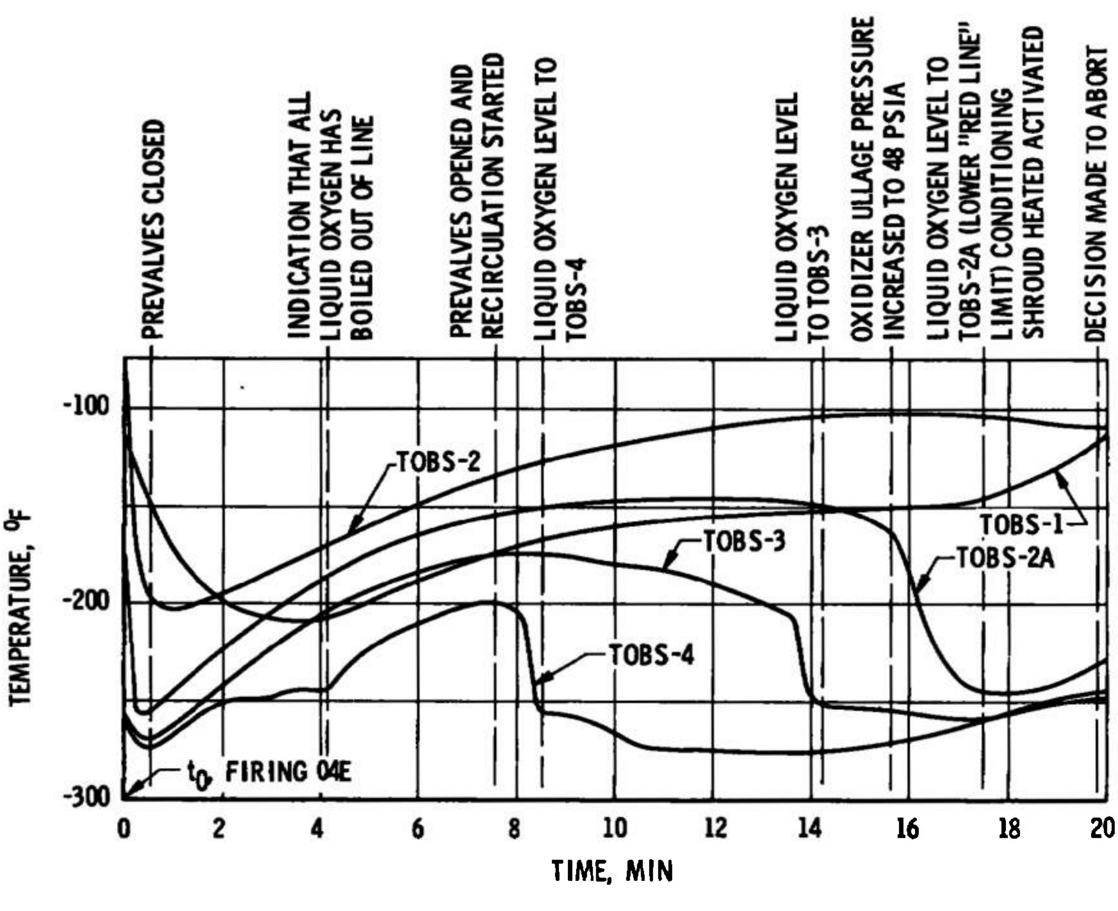



e. Thrust Chamber Conditioning

Fig. 23 Concluded




a. Crossover Duct Cooldown Rate between Firings 04E and 04D




b. Gas Generator Oxidizer Supply Line Temperature History between Firings 04E and 04D

Fig. 24 Gas Generator Oxidizer Supply Line Temperature History between Firing 04E and Firing Attempt 04D

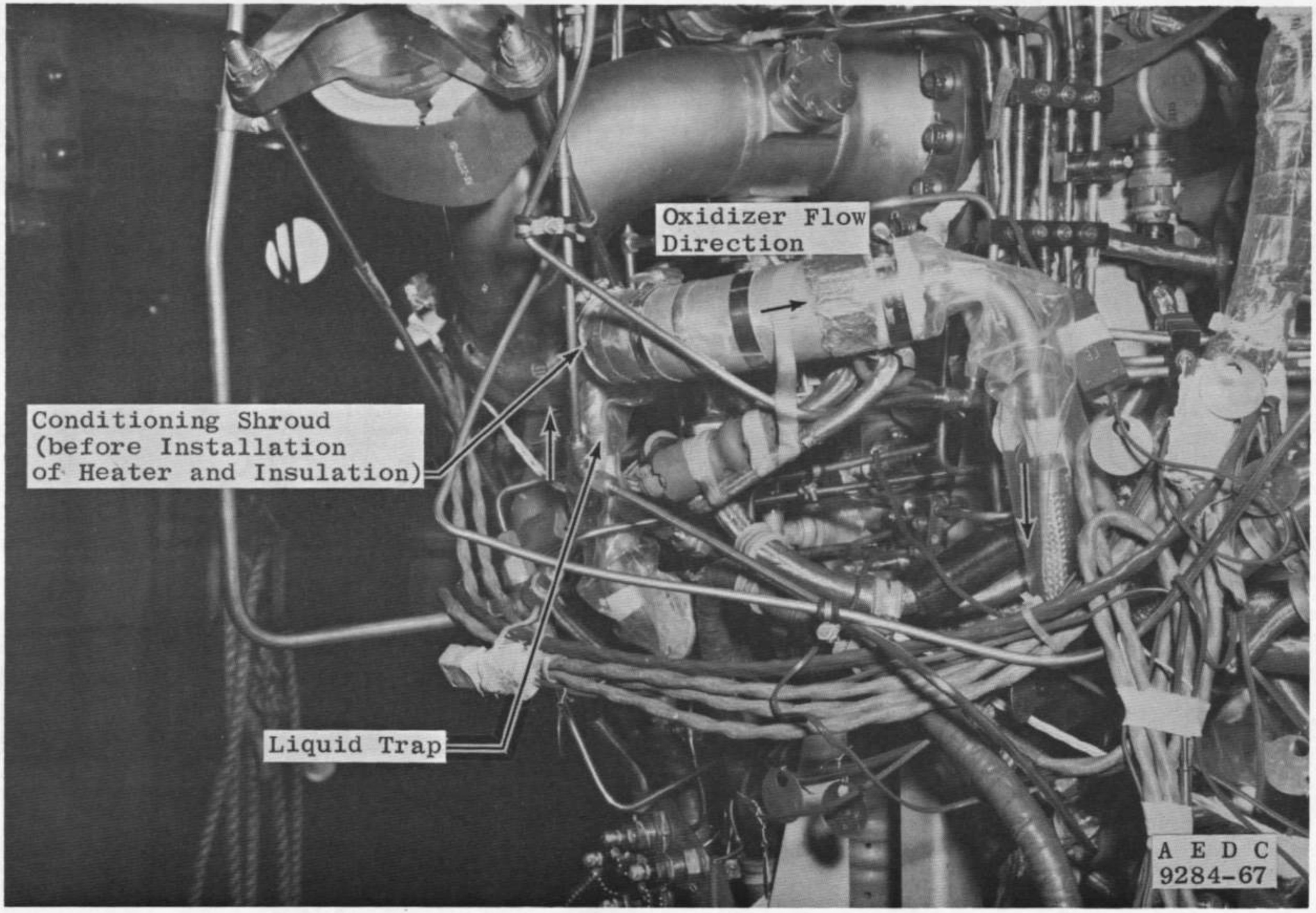



Fig. 25 Gas Generator Oxidizer Supply Line Conditioning Shroud

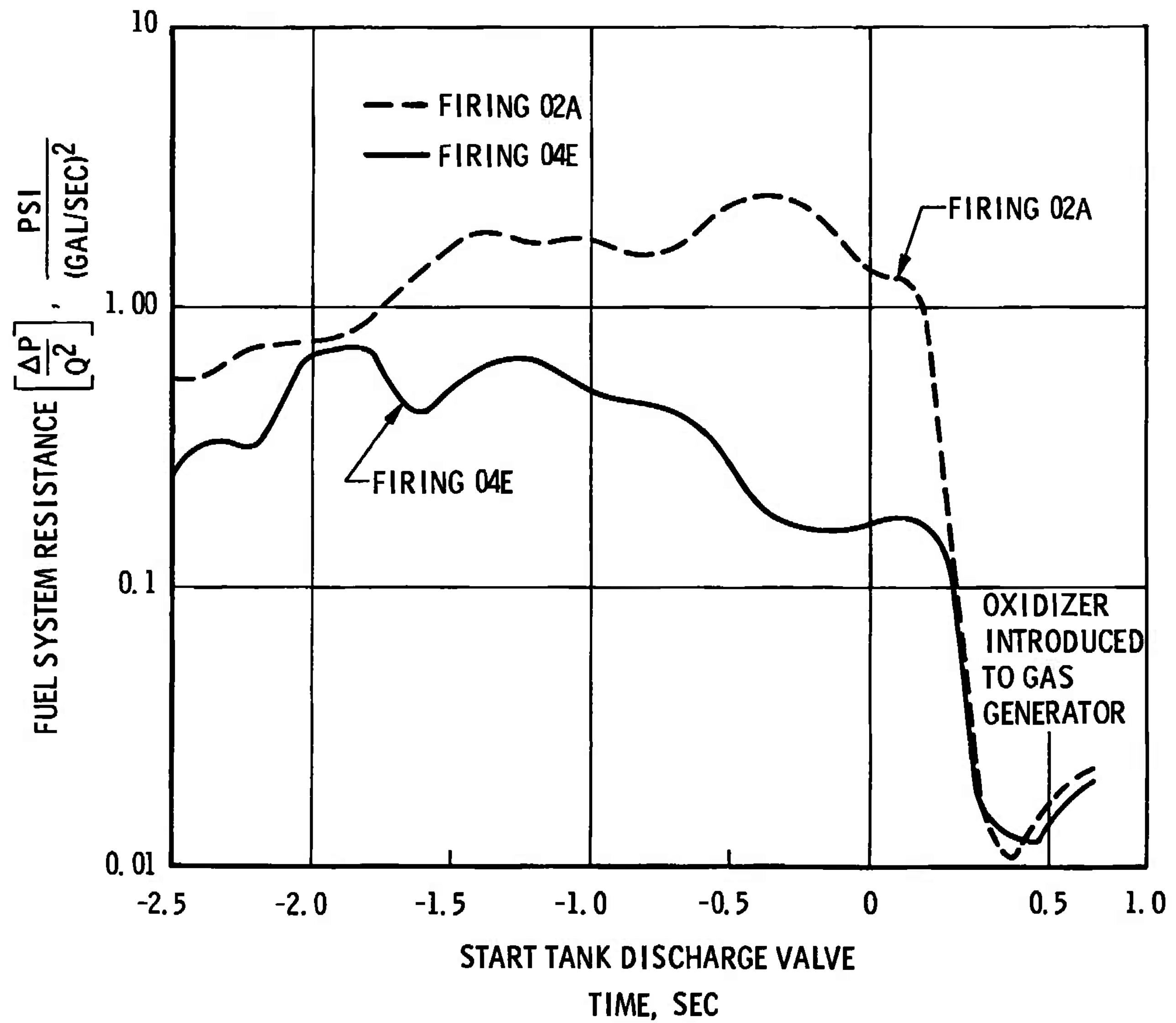



Fig. 26 Fuel System Resistance during Fuel Lead and Gas Generator Ignition Transient for Firings 04E and 02A

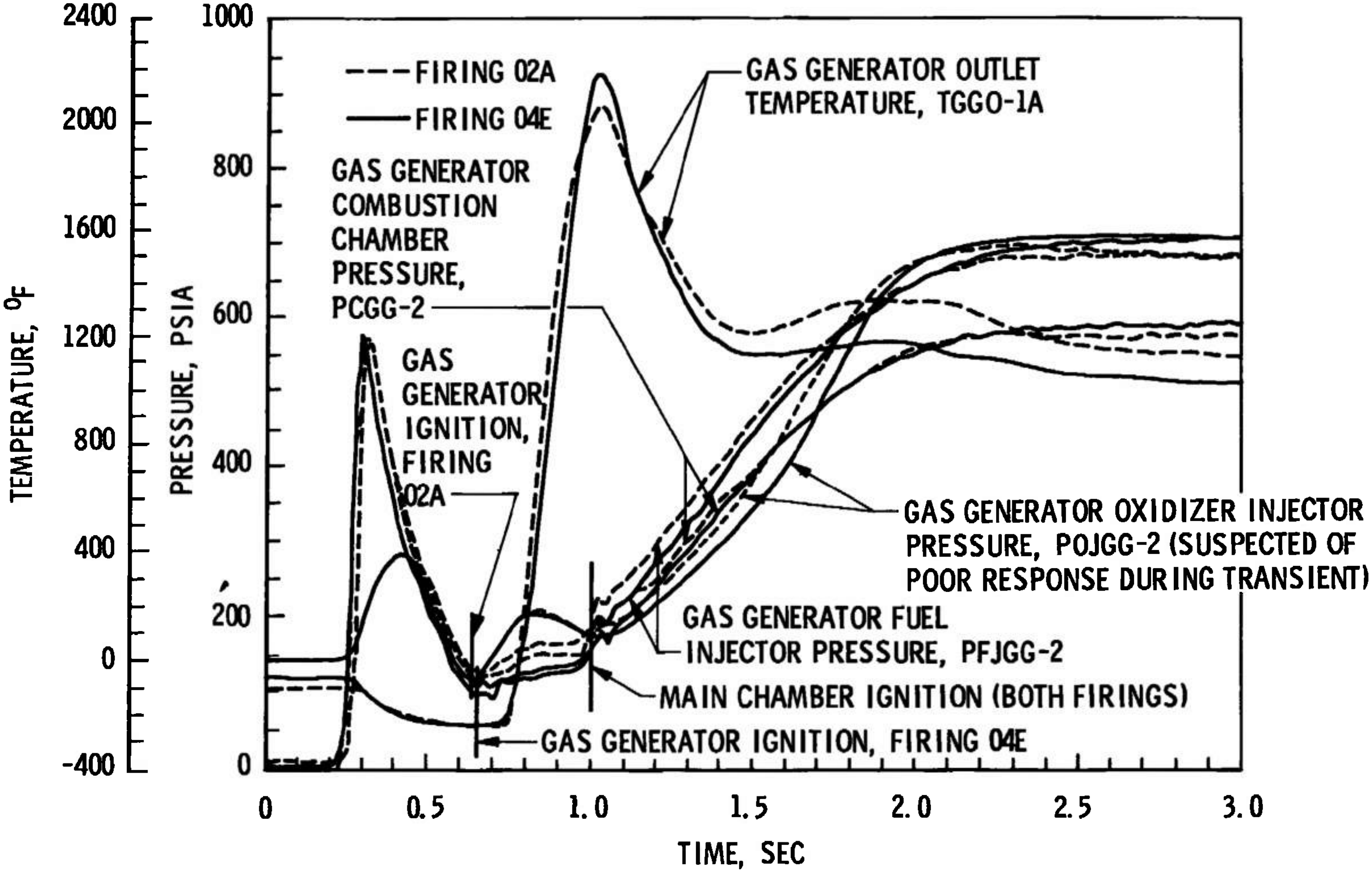
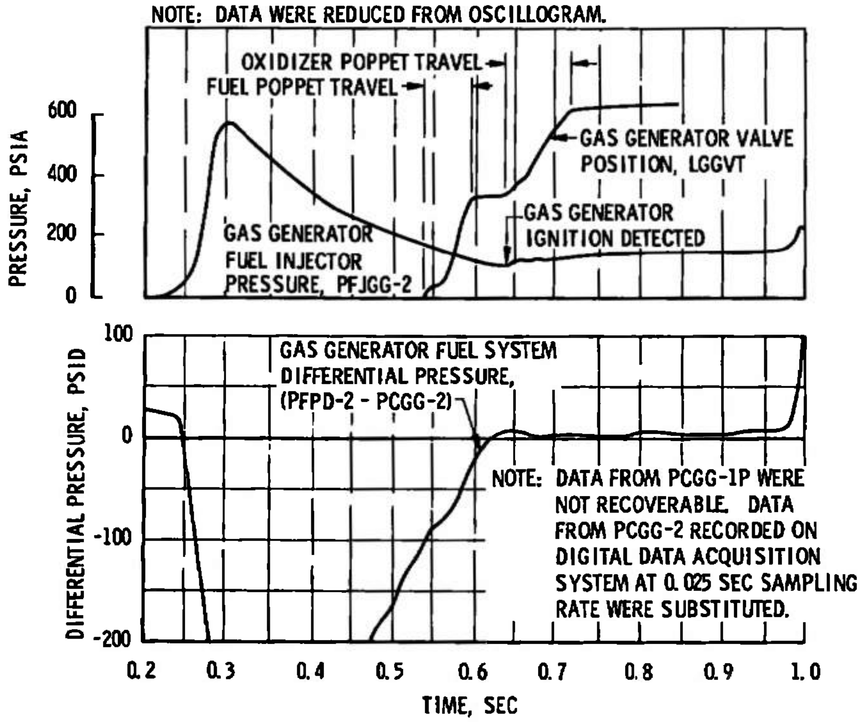
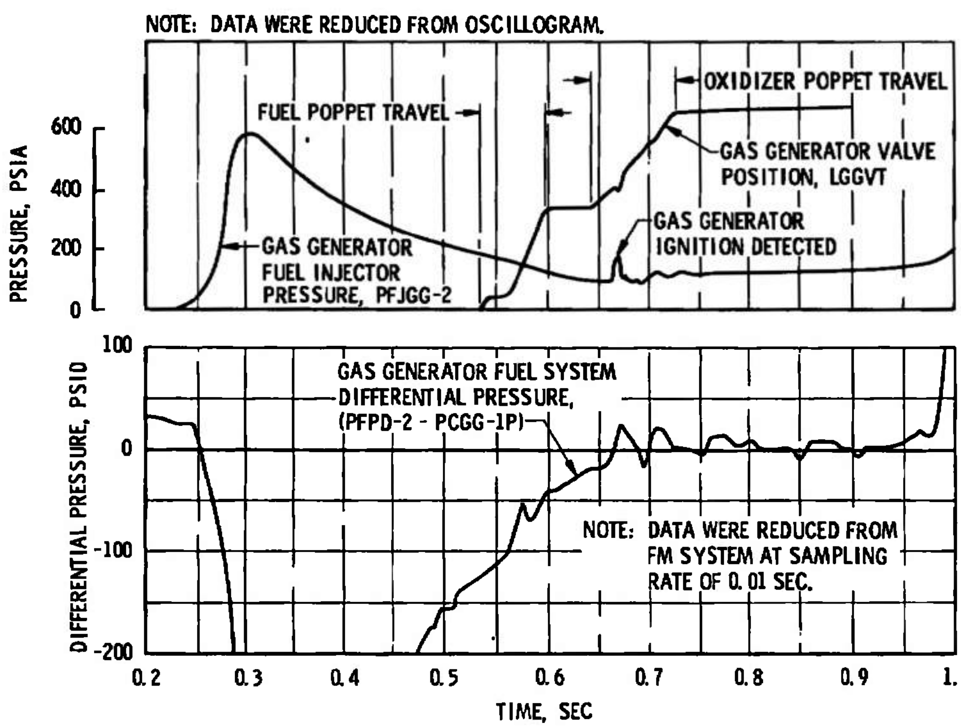



**Fig. 27 Gas Generator Start Transient Comparison, Firings 04E and 02A**

**a. Comparison of Gas Generator Pressures and Temperature, Firings 04E and 02A**

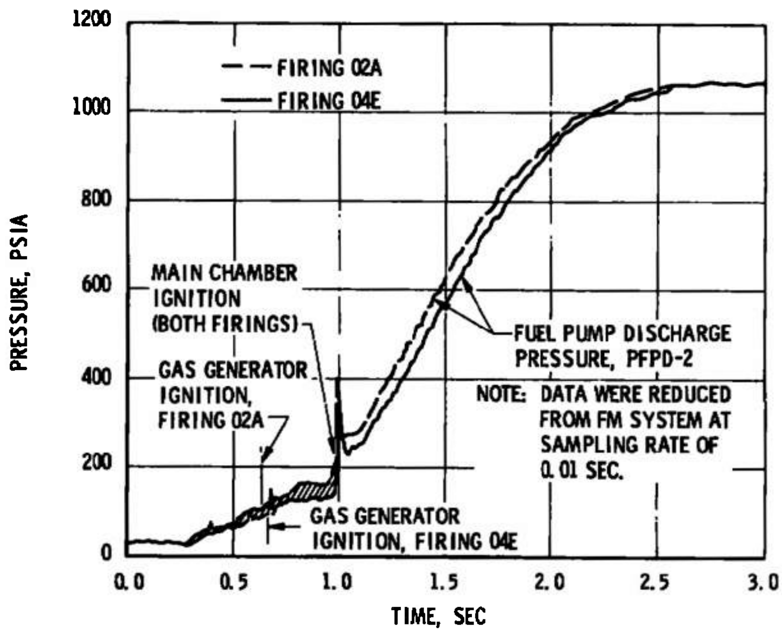



b. Gas Generator Ignition Transient, Firing 02A



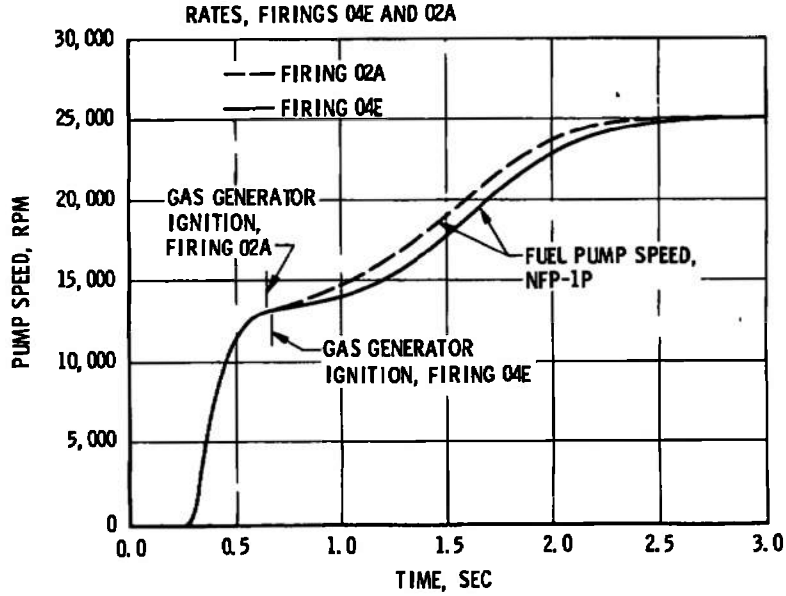

c. Gas Generator Ignition Transient, Firing 04E

Fig. 27 Continued




d. Comparison of Fuel Pump Discharge Pressure Buildup Rates, Firings 04E and 02A

RATES, FIRINGS 04E AND 02A




e. Comparison of Fuel Pump Speed Buildup Rates, Firings 04E and 02A

Fig. 27 Concluded

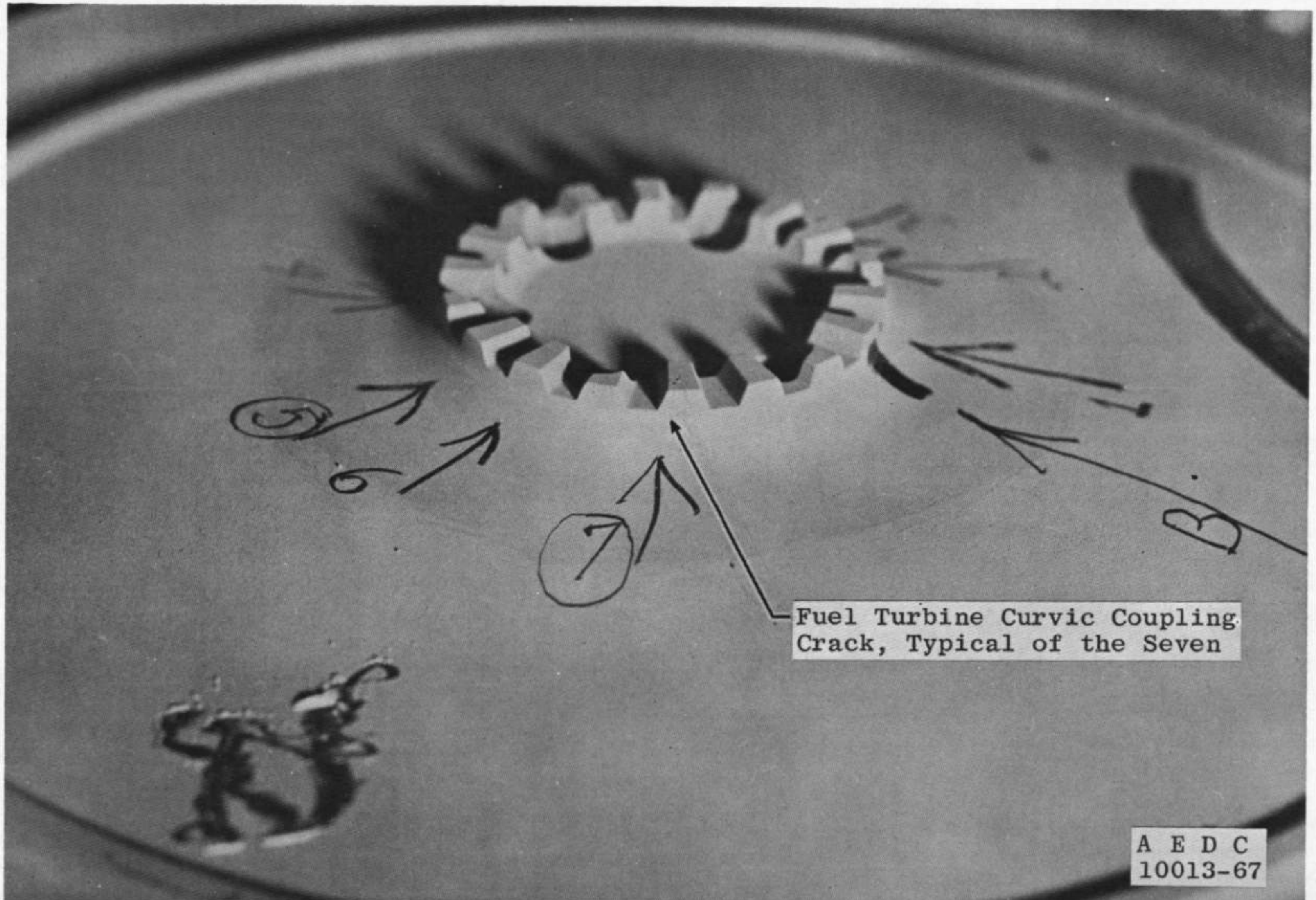



Fig. 28 Fuel Turbine Curvic Coupling Condition, Post-Test J4-1801-04

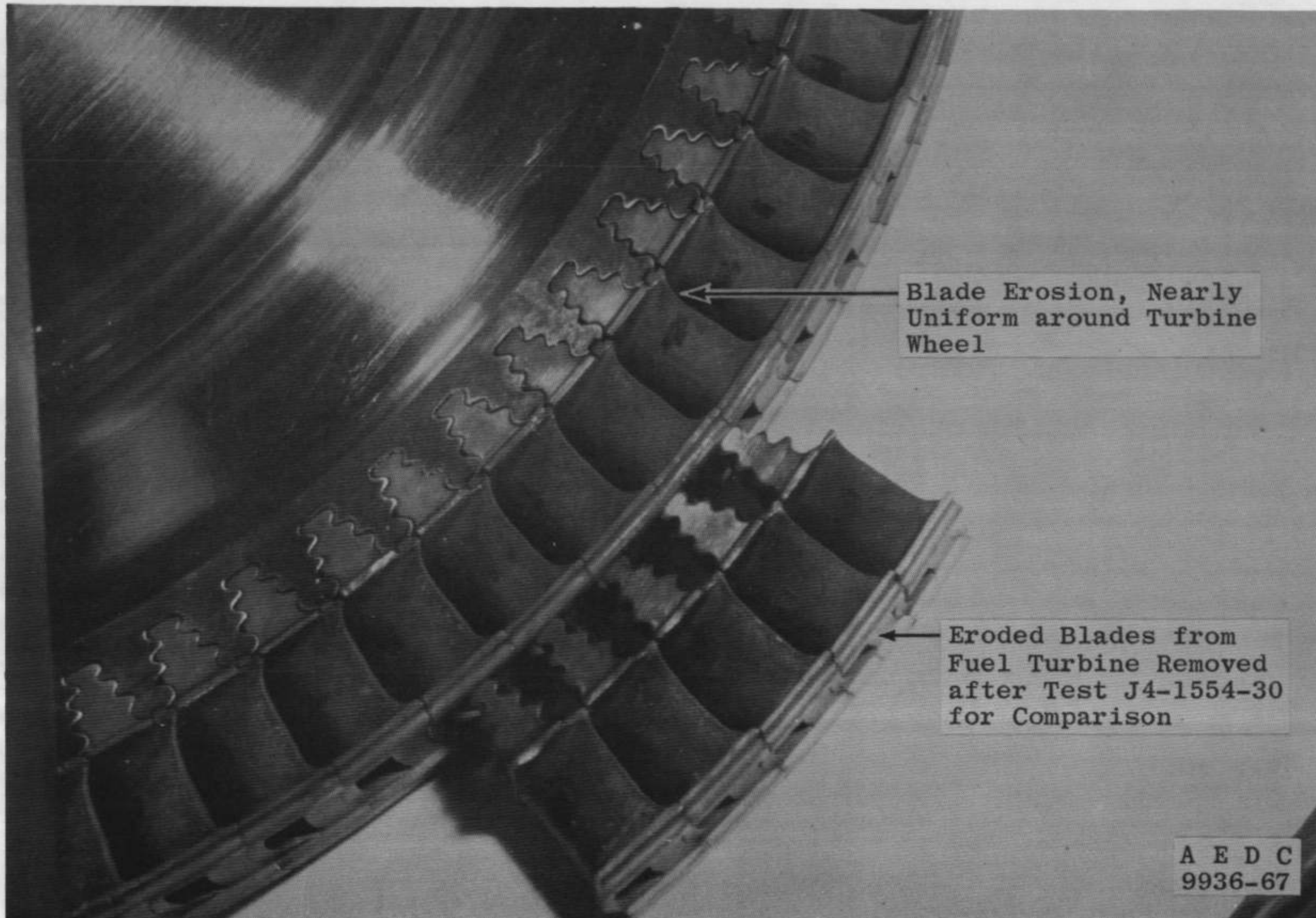



**Fig. 29 Fuel Turbine Blade Condition, Post-Test J4-1801-04**

## TABLE I
## MAJOR ENGINE COMPONENTS

| Part Name | P/N | S/N |
|---|---|---|
| Thrust Chamber Body | 206600-31 | 4076553 |
| Thrust Chamber Injector Assembly | 208021-11 | 4084917 |
| Fuel Turbopump Assembly | 459000-161 | 4062324 |
| Oxidizer Turbopump Assembly | 458175-71 | 6623549 |
| Start Tank | 303439 | 0064 |
| Augmented Spark Igniter | 206280-21 | 3661349 |
| Gas Generator Fuel Injector and Combustor | 308360-11 | 2008734 |
| Pneumatic Control Assembly | 556947 | 4079720 |
| Electrical Control Package | 502670-11 | 4081748 |
| Primary Flight Instrumentation Package | 703685 | 4078716 |
| Auxiliary Flight Instrumentation Package | 703680 | 4078718 |
| Main Fuel Valve | 409120 | 4056924 |
| Main Oxidizer Valve | 411031 | 4089563 |
| Gas Generator Control Valve | 309040 | 4078714 |
| Start Tank Discharge Valve | 306875 | 4079062 |
| Oxidizer Turbine Bypass Valve | 409940 | 4048489 |
| Propellant Utilization Valve | 251351-11 | 4068944 |
| Main-Stage Control Valve | 558069 | 8313568 |
| Ignition Phase Control Valve | 558069 | 8275775 |
| Helium Control Valve | 106012000 | 342270 |
| Start Tank Vent and Relief Valve | 557828-X2 | 4046446 |
| Helium Tank Vent Valve | 106012000 | 342277 |
| Fuel Bleed Valve | 309034 | 4077749 |
| Oxidizer Bleed Valve | 309029 | 4077746 |
| Augmented Spark Igniter Oxidizer Valve | 308880 | 4077205 |
| P/A Purge Control Valve | 557823 | 4073021 |
| Start Tank Fill/Refill Valve | 558000 | 4079001 |
| Fuel Flowmeter | 251225 | 4077752 |
| Oxidizer Flowmeter | 251216 | 4074114 |
| Fuel Injector Temperature Transducer | NA5-27441 | 12401 |
| Restartable Ignition Detect Probe | XEOR915389 | 211 |

**TABLE II**
**SUMMARY OF ENGINE ORIFICES**

| Orifice Name | Part Number | Diameter | Date Effective | Comments |
|---|---|---|---|---|
| Gas Generator Oxidizer Supply Line | RD251-4106 | 0.294 in. | July 31, 1967 | |
| Augmented Spark Igniter Oxidizer Supply Line | 406361 | 0.110 in. | July 12, 1967 | |
| Main Oxidizer Valve Closing Control | 410437 | 8.34 scfm | July 11, 1967 | Thermostatic |
| Oxidizer Turbine Bypass Valve Nozzle | RD273-8002 | 1.571 in. | July 31, 1967 | |
| Gas Generator Fuel Supply Line | RD251-4107 | 0.500 in. | July 31, 1967 | |
| Oxidizer Turbine Exhaust Manifold | RD251-9004 | 9.99 in. | January 18, 1966 | Installed on engine before receipt at AEDC |

## TABLE III
## ENGINE MODIFICATIONS
## (BETWEEN TESTS J4-1801-03 AND J4-1801-04)

| Model Number | Completion Date | Description of Modification | | |
|---|---|---|---|---|
| RFD*-58-67 | July 31, 1967 | Reorificing of Engine as Follows: | | |
| | | Location | From | To |
| | | Gas Generator Fuel, in. | 0.489 | 0.500 |
| | | Gas Generator Oxidizer, in. | 0.284 | 0.294 |
| | | Oxidizer Turbine Bypass Valve, in. | 1.430 | 1.571 |
| RFD-59-67 | August 1, 1967 | Addition of Gas Generator Opening Control Line Flange Thermocouple TSGGOC | | |
| RFD-46-1-67 | August 1, 1967 | Deletion of Start Tank Discharge Valve Closing Control Line Thermocouple TSTDVCC | | |
| RFD-60-67 | August 1, 1967 | Installation of Heater and Insulation on Gas Generator Oxidizer Bootstrap Line | | |
| RFD-44-2-67 | August 1, 1967 | Addition of Oxidizer Bootstrap Line Thermocouple TOBS-2B | | |

*RFD - Rocketdyne Field Directive

## TABLE IV
## ENGINE COMPONENT REPLACEMENTS
## (BETWEEN TESTS J4-1801-03 AND J4-1801-04)

| Model Number | Completion Date | Component Replaced |
|---|---|---|
| UCR*-007972 | August 4, 1967 | Gas Generator Outlet Temperature Transducer |
| UCR-007973 | August 5, 1967 | Fuel Turbine Inlet Temperature Transducer |

*UCR - Rocketdyne Unsatisfactory Condition Report

# TABLE V
## ENGINE PURGE AND COMPONENT CONDITIONING SEQUENCE

Time, min①: t - 80, t - 70, t - 60, t - 50, t - 40, t - 30, t - 20, t - 10, t - 0, t + 10

| | | |
|---|---|---|
| Turbopump and Gas Generator Purge (Purge Manifold System) | Helium; 82 - 125 psia, 50 - 200°F, (Nominal) 6 scfm at Customer Connect | 10 min; Propellant Drop; 2-min Minimum Following Recirculation; 1 to 3 min |
| Oxidizer Dome and Gas Generator Liquid Oxygen Injector (Engine Pneumatic System) | Nitrogen; 400 ± 25 psig, 50 - 200°F, (Minimum) 230 scfm | 15 min; 1 sec (Supplied by Engine Helium Tank during Start and Cutoff Transients) |
| Oxidizer Dome (Facility Line to Port CO3A) | Nitrogen; 400 - 450 psig, 100 - 200°F, (Nominal) 200 scfm | 45 min; On at Engine Cutoff; 10 min |
| Oxidizer Turbopump Intermediate Seal Cavity (Engine Pneumatic System) | Helium; 400 ± 25 psig, Ambient Temperature, 2600 - 7000 scfm | 15 min; Main-Stage Operation (Supplied by Engine Helium Tank) |
| Thrust Chamber Jacket (Customer Connect) Panel | Helium; 40 - 60 psig, 50 - 200°F, (Nominal) 60 scfm | In Addition to; 15 min |
| | Helium; 12 - 14 psig, 50 - 200°F, (Nominal) 10 scfm | On at Engine Cutoff; 10 min |
| Thrust Chamber Temperature Conditioning | Helium; 1000 psig, -300°F to Ambient, 10 - 20 $lb_m$/min | 15 min |
| Pump Inlet Pressure and Temperature Conditioning | Oxidizer; 35 to 48 psia, -298 to -280°F; Fuel; 28 to 46 psia, -424 to -416°F | |
| Hydrogen Start Tank and Helium Tank Pressure and Temperature Conditioning | Hydrogen; 1200 to 1400 psia, -300 to -140°F; Helium; 1700 to 3250 psia, -300 to -140°F | 46 min |
| Crossover Duct Temperature Conditioning | Helium; -300°F to Ambient | ③ |
| Main Oxidizer Valve Actuator Temperature Conditioning | Helium; -300°F to Ambient | ② |
| Main Oxidizer Valve Closing Control Line (Conditioning) | Helium; -300°F to Ambient | ③ |
| Pneumatic Regulator Temperature Conditioning | Helium; -300°F to Ambient | ② |

①Times are adjusted for one and two orbit simulation firings

②Component conditions to be maintained within limits for last 30 min before engine start or coast duration, whichever is longer.

③Component conditions to be maintained within limits for last 15 min before engine start.

## TABLE VI
## SUMMARY OF TEST REQUIREMENTS AND RESULTS

| Firing Number, J4-1801- | | 04A Target | 04A Actual | 04C Target | 04C Actual | 04B Target | 04B Actual | 04E Target | 04E Actual |
|---|---|---|---|---|---|---|---|---|---|
| Time of Day, hr/Firing Date | | 1242/August 3, 1967 | | 1510/August 3, 1967 | | 1530/August 3, 1967 | | 2034/August 3, 1887 | |
| Pressure Altitude at Engine Start, ft (Ref. 1) | | --- | 100,000 | --- | 108,000 | --- | 109,500 | --- | 107,000 |
| Firing Duration, sec① | | 30.0 | 30.07 | 30.0 | 30.07 | 5.0 | 5.09 | 30.0 | 30.07 |
| Fuel Pump Inlet Conditions at Engine Start | Pressure, psia | 28.0 ± 1.0 | 30.0 | 28.0 ± 1.0 | 28.3 | 28.0 ± 1.0 | 27.8 | 28.0 ± 1.0 | 30.2 |
| | Temperature, °F | -420.4 ± 0.4 | -420.1 | -420.4 ± 0.4 | -420.3 | -421.4 ± 0.4 | -420.5 | -420.4 ± 0.4 | -420.7 |
| Oxidizer Pump Inlet Conditions at Engine Start | Pressure, psia | 48.0 ± 1.0 | 48.1 | 35.0 ± 1.0 | 35.1 | 48.0 ± 1.0 | 47.9 | 48.0 ± 1.0 | 48.4 |
| | Temperature, °F | -285.3 ± 0.4 | -288.5 | -284.0 ± 0.4 | -284.6 | -285.3 ± 0.4 | -285.5 | -295.3 ± 0.4 | -298.0 |
| Start Tank Conditions at Engine Start | Pressure, psia | 1400 ± 10 | 1385 | 1250 ± 10 | 1248 | 1400 ± 10 | 1409 | 1400 ± 10 | 1388 |
| | Temperature, °F | -200 ± 10 | -197 | -140 ± 10 | -144 | -240 ± 10 | -238 | -200 ± 10 | -206 |
| Helium Tank Conditions at Engine Start | Pressure, psia | --- | 2412 | --- | 2219 | --- | 2090 | --- | 2475 |
| | Temperature, °F | --- | -202 | --- | -148 | --- | -235 | --- | -210 |
| Thrust Chamber Temperature Conditions at Engine Start, °F | Throat | -200 ± 15 | -189 | -100 ± 15 | -121 | --- | 51 | -200 ± 15 | -201 |
| | Average | --- | -175 | --- | -121 | --- | 8 | --- | -197 |
| Crossover Duct Temperature at Engine Start, °F① | TFTD-2 | -20 ± 15 | -50 | -100 ± 15 | -131 | --- | 417 | -20 ± 15 | -47 |
| | TFTD-3 | | -25 | | -120 | $170^{+15}_{-0}$ | 176 | | -26 |
| | TFTD-8 | | -30 | | -105 | --- | 371 | | -32 |
| Main Oxidizer Valve Closing Control Line Temperature at Engine Start, °F② | | -100 ± 10 | -102 | -50 ± 10 | -55 | -150 ± 10 | -160 | -100 ± 10 | -113 |
| Main Oxidizer Valve Second-Stage Actuator Temperature at Engine Start, °F② | | -175 ± 10 | -158 | -150 ± 10 | -142 | -225 ± 10 | -221 | -175 ± 10 | -178 |
| Pneumatic Control Package Temperature at Engine Start, °F① | | -100 ± 10 | -100 | -50 ± 10 | -57 | -150 ± 10 | -163 | -100 ± 10 | -108 |
| Fuel Lead Time, sec① | | 3 | 3.007 | 8 | 7.995 | 8 | 7.980 | 3 | 3.008 |
| Propellant in Engine Time, min | | 80 | 118 | 20 | 88 | 10 | 11 | 80 | 74 |
| Propellant Recirculation Time, min | | 10 | 10.5 | 10 | 11 | 10 | 11 | 10 | 16.5 / 10.5 |
| Sequencing Logic | | Auxiliary | Auxiliary | Normal | Normal | Normal | Normal | Auxiliary | Auxiliary |
| Gas Generator Oxidizer Supply Line Temperature at Engine Start, °F | TOBS-1 | -50 ± 10 | ④ | -50 ± 10 | ④ | -50 ± 10 | ④ | Duplication of Firing 02A Conditions | ④ |
| | TOBS-2 | | | | | | | | |
| | TOBS-3 | | | | | | | | |
| Start Tank Discharge Valve Opening Control Temperature at Engine Start, °F | | --- | -54 | --- | -58 | --- | -57 | --- | -75 |
| Gas Generator Control Valve Opening Control Temperature at Engine Start, °F | | --- | -105 | --- | -82 | --- | -127 | --- | -118 |
| Vibration Safety Count Duration (msec) and Occurrence Time (sec) from Start Tank Discharge Valve | | --- | 87 at 0.984 | --- | 4 at 0.544 / 15 at 1.083 | --- | None | --- | 33 at 0.878 |
| Gas Generator Outlet Temperature, °F | Initial Peak | --- | 2038 | --- | 1094 | --- | 2121 | --- | 2201 |
| | Second Peak | --- | None | --- | None | --- | None | --- | None |
| Thrust Chamber Ignition Time, sec (Ref. $t_0$) ($P_c$ - 3 = 100 psia)① | | --- | 1.003 | --- | 1.100 | --- | 0.848 | --- | 0.878 |
| Main Oxidizer Valve Second-Stage Initial Movement, sec (Ref. $t_0$)① | | --- | 0.885 | --- | 1.028 | --- | 1.098 | --- | 0.985 |
| Main-Stage Pressure No. 2, sec (Ref. $t_0$)① | | --- | 1.638 | --- | 2.041 | --- | 1.568 | --- | 1.631 |
| 550-psia Chamber Pressure Attained, sec (Ref. Start Tank Discharge Valve) | | --- | 1.802 | --- | 2.758 | --- | 1.915 | --- | 1.885 |

Notes: ① Data reduced from oscillogram.
② Component conditioning to be maintained within limits for last 15 min before engine start.
③ Component conditioning to be maintained within limits for last 30 min before engine start or coast duration, whichever is longer.
④ See Table VIII.

# TABLE VII
## ENGINE VALVE TIMINGS

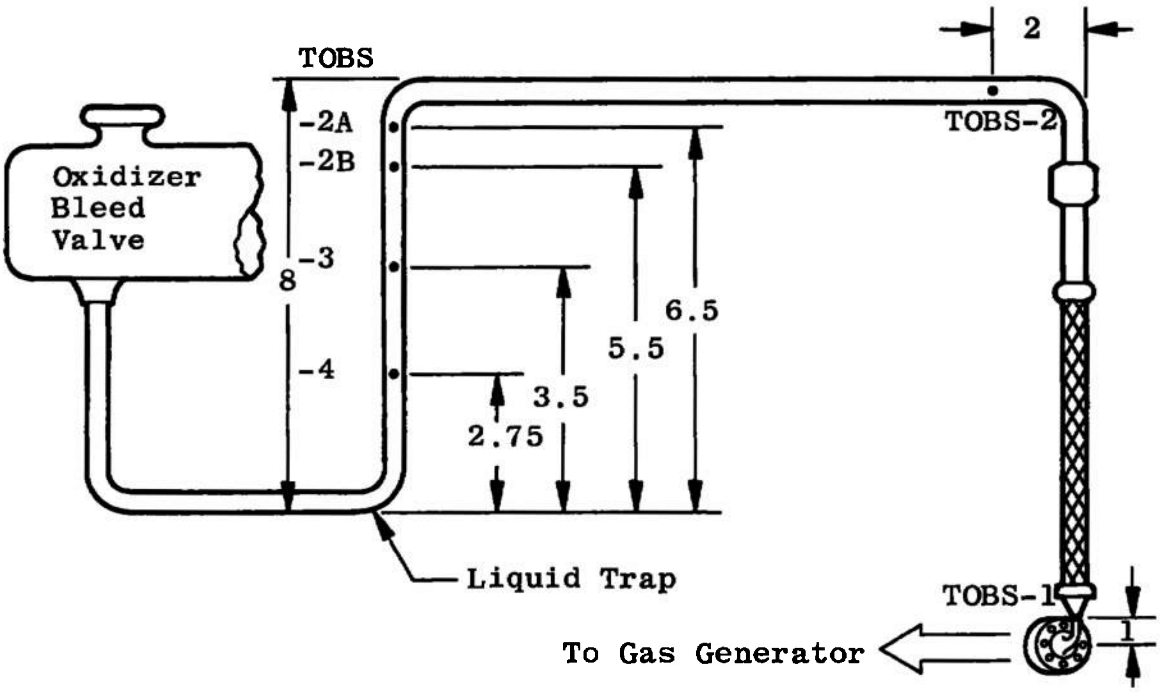
| Firing Number J4-1901- | Start: Start Tank Discharge Valve | | | | | | Main Fuel Valve | | | Main Oxidizer Valve First Stage | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Time of Opening Signal | Valve Delay Time, sec | Valve Opening Time, sec | Time of Closing Signal | Valve Delay Time, sec | Valve Closing Time, sec | Time of Opening Signal | Valve Delay Time, sec | Valve Opening Time, sec | Time of Opening Signal | Valve Delay Time, sec | Valve Opening Time, sec |
| -04A | 0 | 0.155 | 0.149 | 0.445 | 0.097 | 0.263 | -3.007 | 0.058 | 0.062 | 0.445 | 0.054 | 0.049 |
| -04B | 0 | 0.154 | 0.152 | 0.443 | 0.091 | 0.258 | -7.880 | 0.059 | 0.057 | 0.443 | 0.052 | 0.045 |
| -04C | 0 | 0.147 | 0.134 | 0.447 | 0.089 | 0.268 | -7.995 | 0.046 | 0.067 | 0.447 | 0.053 | 0.047 |
| -04E | 0 | 0.160 | 0.150 | 0.445 | 0.097 | 0.268 | -3.008 | 0.055 | 0.063 | 0.445 | 0.052 | 0.049 |
| Pre-Fire Final Sequence | 0 | 0.099 | 0.106 | 0.447 | 0.093 | 0.249 | -1.010 | 0.047 | 0.062 | 0.447 | 0.049 | 0.045 |

| Firing Number J4-1901- | Start: Main Oxidizer Valve Second Stage | | | Gas Generator Fuel Poppet | | | Gas Generator Oxidizer Poppet | | | Oxidizer Turbine Bypass Valve | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Time of Opening Signal | Valve Delay Time, sec | Valve Opening Time, sec | Time of Opening Signal | Valve Delay Time, sec | Valve Opening Time, sec | Time of Opening Signal | Valve Delay Time, sec | Valve Opening Time, sec | Time of Closing Signal | Valve Delay Time, sec | Valve Closing Time, sec |
| -04A | 0.445 | 0.540 | 1.939 | 0.445 | 0.090 | 0.060 | 0.445 | 0.194 | 0.075 | 0.445 | 0.238 | 0.294 |
| -04B | 0.443 | 0.655 | 1.644 | 0.443 | 0.091 | 0.090 | 0.443 | 0.205 | 0.087 | 0.443 | 0.237 | 0.290 |
| -04C | 0.447 | 0.591 | 1.649 | 0.447 | 0.091 | 0.058 | 0.447 | 0.199 | 0.079 | 0.447 | 0.250 | 0.299 |
| -04E | 0.445 | 0.540 | 1.725 | 0.445 | 0.090 | 0.060 | 0.445 | 0.185 | 0.086 | 0.445 | 0.243 | 0.310 |
| Pre-Fire Final Sequence | 0.447 | 0.577 | 1.712 | 0.447 | 0.073 | 0.045 | 0.447 | 0.139 | 0.056 | 0.447 | 0.210 | 0.287 |



| Firing Number J4-1801- | Shutdown: Main Fuel Valve | | | Main Oxidizer Valve | | | Gas Generator Fuel Poppet | | | Gas Generator Oxidizer Poppet | | | Oxidizer Turbine Bypass Valve | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Time of Closing Signal | Valve Delay Time, sec | Valve Closing Time, sec | Time of Closing Signal | Valve Delay Time, sec | Valve Closing Time, sec | Time of Closing Signal | Valve Delay Time, sec | Valve Closing Time, sec | Time of Closing Signal | Valve Delay Time, sec | Valve Closing Time, sec | Time of Opening Signal | Valve Delay Time, sec | Valve Opening Time, sec |
| -04A | 30.07 | 0.124 | 0.292 | 30.07 | 0.086 | 0.199 | 30.07 | 0.068 | 0.034 | 30.07 | 0.019 | 0.025 | 30.07 | 0.270 | 0.538 |
| -04B | 5.09 | 0.108 | 0.317 | 5.09 | 0.077 | 0.199 | 5.09 | 0.073 | 0.023 | 5.09 | 0.022 | 0.029 | 5.09 | 0.254 | 0.538 |
| -04C | 30.07 | 0.112 | 0.307 | 30.07 | 0.078 | 0.185 | 30.07 | 0.072 | 0.021 | 30.07 | 0.018 | 0.021 | 30.07 | 0.278 | 0.573 |
| -04E | 30.07 | 0.121 | 0.325 | 30.07 | 0.083 | 0.199 | 30.07 | 0.068 | 0.030 | 30.07 | 0.020 | 0.026 | 39.07 | 0.268 | 0.568 |
| Pre-Fire Final Sequence | --- | 0.099 | 0.239 | --- | 0.053 | 0.128 | --- | 0.090 | 0.028 | --- | 0.063 | 0.018 | 30.07<br>--- | 0.229 | 0.594 |

Notes:
1. All valve signal times are referenced to $t_0$.
2. Valve delay time is the time required for initial valve movement after the valve open or closed solenoid has been energized.
3. Final sequence check is conducted without propellants and within 12 hr before testing.
4. Data reduced from oscillogram.




All Dimensions in Inches

TABLE VIII
GAS GENERATOR OXIDIZER SUPPLY LINE TEMPERATURES AT ENGINE START

| Parameter | 04A | 04C | 04B | 04E | 04D |
|---|---|---|---|---|---|
| TOBS-1, °F | -37 | -23 | -43 | -112 | -129 |
| TOBS-2, °F | -39 | -26 | -38 | -73 | -109 |
| TOBS-2A, °F | -52 | -34 | -53 | -176 | -240 |
| TOBS-2B, °F | -46 | -31 | -45 | -162 | -163 |
| TOBS-3, °F | -83 | -58 | -88 | -254 | -251 |
| TOBS-4, °F | -174 | -112 | -182 | -258 | -249 |

Note: Thermocouple TOBS-2B was suspected of poor contact with the line.

## TABLE IX
## TEST CONDITION COMPARISONS

| Firing Number J4-1801- | | 02A | 04A | 03A | 04E | 03B | 04B | 04D* |
|---|---|---|---|---|---|---|---|---|
| Fuel Pump Inlet Conditions at Engine Start | Pressure, psia | 28.3 | 30.0 | 29.6 | 30.2 | 28.3 | 27.6 | --- |
| | Temperature, °F | -420.4 | -420.1 | -420.6 | -420.7 | -420.6 | -420.5 | --- |
| Oxidizer Pump Inlet Conditions at Engine Start | Pressure, psia | 47.7 | 48.1 | 48.6 | 48.4 | 47.8 | 47.9 | --- |
| | Temperature, °F | -295.8 | -296.5 | -294.6 | -296.0 | -294.3 | -295.5 | --- |
| Start Tank Conditions at Engine Start | Pressure, psia | 1395 | 1395 | 1394 | 1399 | 1401 | 1409 | 1399 |
| | Temperature, °F | -203 | -197 | -203 | -206 | -243 | -236 | -239 |
| Thrust Chamber Temperature, °F | Throat at Engine Start | -115 | -169 | -186 | -201 | 110 | 51 | 73 |
| | Average at $t_0$ | -147 | -231 | -243 | -257 | -182 | -176 | --- |
| Crossover Duct Temperature at Engine Start | TFTD-3, °F | -17 | -25 | -38 | -32 | 181 | 176 | 179 |
| Main Oxidizer Valve Closing Control Line Temperature at Engine Start | | -96 | -102 | -132 | -113 | -163 | -160 | -171 |
| Main Oxidizer Valve Second-Stage Actuator Temperature at Engine Start | | -166 | -159 | -299 | -176 | -321 | -221 | -252 |
| Pneumatic Control Package Temperature at Engine Start | | -116 | -100 | -95 | -108 | -178 | -163 | -168 |
| Gas Generator Oxidizer Supply Line Temperature, °F | TOBS-1 | -76 | -37 | -134 | -112 | -126 | -43 | -129 |
| | TOBS-2 | -50 | -39 | -159 | -73 | -182 | -38 | -109 |
| | TOBS-2A | --- | -52 | -249 | -176 | -265 | -53 | -240 |
| | TOBS-3 | -252 | -83 | -261 | -254 | -262 | -88 | -251 |
| | TOBS-4 | -248 | -174 | -256 | -258 | -253 | -182 | -249 |
| Propellant in Engine Time, min | | 116 | 118 | 143 | 74 | 10 | 11 | 12 |
| Oxidizer Recirculation Time, min | | 11 | 10.5 | 11 | 16.5 / 10.5 | 10 | 11 | 12 |
| Oxidizer System Pressurized, min | | 2 | 2 | 2 | 1 / 2 | 2.4 | 2.5 | 4.5 |
| Fuel Lead Time, sec | | 3.000 | 3.007 | 3.002 | 3.008 | 7.992 | 7.980 | --- |
| Actual Coast Time before Engine Restart (80-min Simulation), min | | N/A | N/A | N/A | N/A | 19 | 19 | 19 |
| Gas Generator Peak Temperature, °F | | 2080 | 2040 | 2490 | 2200 | **2650 | 2120 | --- |

*Conditions shown for t - 1 sec countdown time when firing 04D was aborted.

**The gas generator temperature sensing probe failed, producing engine cutoff at $t_0$ + 1.25 sec.

## TABLE X
## ENGINE PERFORMANCE SUMMARY

| Firing Number J4-1801- | | 04A | | 04C | | 04E | |
|---|---|---|---|---|---|---|---|
| Time | | 29.5 | | 29.5 | | 29.5 | |
| | | Site | Normalized | Site | Normalized | Site | Normalized |
| Overall Engine Performance | Thrust, lbf | 230,900 | 228,100 | 229,600 | 227,500 | 228,600 | 225,600 |
| | Chamber Pressure, psia | 778.1 | 766.8 | 773.3 | 764.5 | 770.8 | 758.3 |
| | Mixture Ratio | 5.616 | 5.547 | 5.572 | 5.537 | 5.585 | 5.540 |
| | Oxidizer Weight Flow, $lb_m$/sec | 461.7 | 453.2 | 457.3 | 451.2 | 458.9 | 450.5 |
| | Fuel Weight Flow, $lb_m$/sec | 82.2 | 81.7 | 82.0 | 81.5 | 82.2 | 81.3 |
| | Total Weight Flow, $lb_m$/sec | 543.9 | 534.9 | 539.3 | 532.7 | 541.1 | 531.8 |
| Thrust Chamber Performance | Mixture Ratio | 5.834 | 5.766 | 5.788 | 5.755 | 5.802 | 5.760 |
| | Total Weight Flow, $lb_m$/sec | 536.6 | 527.6 | 532.0 | 525.4 | 533.8 | 524.5 |
| | Characteristic Velocity, ft/sec | 7948 | 7966 | 7967 | 7975 | 7914 | 7924 |
| Fuel Turbopump Performance | Pump Efficiency, percent | 72.4 | 72.4 | 72.4 | 72.4 | 72.7 | 72.7 |
| | Pump Speed, rpm | 27,022 | 26,656 | 26,863 | 26,567 | 27,003 | 26,650 |
| | Turbine Efficiency, percent | 58.2 | 58.0 | 58.1 | 57.9 | 59.3 | 59.1 |
| | Turbine Pressure Ratio | 7.36 | 7.36 | 7.35 | 7.35 | 7.30 | 7.24 |
| | Turbine Inlet Temperature, °F | 1278 | 1238 | 1266 | 1234 | 1252 | 1217 |
| | Turbine Weight Flow, $lb_m$/sec | 7.35 | 7.30 | 7.28 | 7.25 | 7.30 | 7.24 |
| Oxidizer Turbopump Efficiency | Pump Efficiency, percent | 80.4 | 80.3 | 80.4 | 80.3 | 80.3 | 80.3 |
| | Pump Speed, rpm | 8591 | 8534 | 8577 | 8516 | 8586 | 8522 |
| | Turbine Efficiency, percent | 45.7 | 45.6 | 46.1 | 46.0 | 45.8 | 45.8 |
| | Turbine Pressure Ratio | 2.73 | 2.73 | 2.72 | 2.72 | 2.73 | 2.73 |
| | Turbine Inlet Temperature, °F | 806 | 777 | 792 | 771 | 783 | 759 |
| | Turbine Weight Flow, $lb_m$/sec | 6.37 | 6.33 | 6.31 | 6.28 | 6.32 | 6.26 |
| Gas Generator Performance | Mixture Ratio | 0.986 | 0.962 | 0.979 | 0.961 | 0.971 | 0.950 |
| | Chamber Pressure, psia | 700.2 | 684.4 | 693.0 | 679.2 | 693.1 | 676.4 |

Site - Test Data

Normalized - Test Data Corrected to Standard Pump Inlet and Engine Ambient Vacuum Conditions

## APPENDIX III
## INSTRUMENTATION

The instrumentation for AEDC test J4-1801-04 is tabulated in Table III-1. The location of selected major engine instrumentation is shown in Fig. III-1.

## TABLE III-1
## INSTRUMENTATION LIST

| AEDC Code | Parameter | Tap No. | Range | Micro-SADIC | Magnetic Tape | Oscillo-graph | Strip Chart | X-Y Plotter |
|---|---|---|---|---|---|---|---|---|
| | Current | | amp | | | | | |
| ICC | Control | | 0 to 30 | x | | x | | |
| IIC | Ignition | | 0 to 30 | x | | x | | |
| | Event | | | | | | | |
| EECL | Engine Cutoff Lockin | | On/Off | x | | x | | |
| EECO | Engine Cutoff Signal | | On/Off | x | x | x | | |
| EES | Engine Start Command | | On/Off | x | | x | | |
| EFBVC | Fuel Bleed Valve Closed Limit | | Open/Closed | x | | | | |
| EFJT | Fuel Injector Temperature | | On/Off | x | | x | | |
| EFPVC/O | Fuel Prevalve Closed/Open Limit | | Closed/Open | x | | x | | |
| EHCS | Helium Control Solenoid | | On/Off | x | | x | | |
| EID | Ignition Detected | | On/Off | x | | x | | |
| EIPCS | Ignition Phase Control Solenoid | | On/Off | x | | x | | |
| EMCS | Main-Stage Control Solenoid | | On/Off | x | | x | | |
| EMP-1 | Main-Stage Pressure No. 1 | | On/Off | x | | x | | |
| EMP-2 | Main-Stage Pressure No. 2 | | On/Off | x | | x | | |
| EOBVC | Oxidizer Bleed Valve Closed Limit | | Open/Closed | x | | | | |
| EOPVC | Oxidizer Prevalve Closed Limit | | Closed | x | | x | | |
| EOPVO | Oxidizer Prevalve Open Limit | | Open | x | | x | | |
| ESTDCS | Start Tank Discharge Control Solenoid | | On/Off | x | x | x | | |
| | Sparks | | | | | | | |
| RASIS-1 | Augmented Spark Igniter Spark No. 1 | | On/Off | | | x | | |
| RASIS-2 | Augmented Spark Igniter Spark No. 2 | | | | | x | | |
| RGGS-1 | Gas Generator Spark No. 1 | | On/Off | | | x | | |
| RGGS-2 | Gas Generator Spark No. 2 | | On/Off | | | x | | |
| | Flows | | gpm | | | | | |
| QF-1A | Fuel | PFF | 0 to 9000 | x | | x | | |
| QF-2 | Fuel | PFFA | 0 to 9000 | x | x | x | | |
| QF-2SD | Fuel Flow Stall Approach Monitor | | 0 to 9000 | x | | x | | |
| QFRP | Fuel Recirculation | | 0 to 160 | x | | | | |
| QO-1A | Oxidizer | POF | 0 to 3000 | x | | x | | |
| QO-2 | Oxidizer | POFA | 0 to 3000 | x | x | x | | |
| QORP | Oxidizer Recirculation | | 0 to 50 | x | | | x | |
| | Forces | | lbf | | | | | |
| FSP-1 | Side Load (Pitch) | | ±20,000 | x | | x | | |
| FSY-1 | Side Load (Yaw) | | ±20,000 | x | | x | | |
| | Position | | Percent Open | | | | | |
| LFVT | Main Fuel Valve | | 0 to 100 | x | | x | | |
| LGGVT | Gas Generator Valve | | 0 to 100 | x | | x | | |
| LOTBVT | Oxidizer Turbine Bypass Valve | | 0 to 100 | x | | x | | |
| LOVT | Main Oxidizer Valve | | 0 to 100 | x | x | x | | |
| LPUTOP | Propellant Utilization Valve (Pot Output Voltage) | | 0 to 100 | x | | x | x | |
| LSTDVT | Start Tank Discharge Valve | | 0 to 100 | x | | x | | |

## TABLE III-1 (Continued)

| AEDC Code | Parameter | Tap No. | Range | Micro-SADIC | Magnetic Tape | Oscillograph | Strip Chart | X-Y Plotter |
|---|---|---|---|---|---|---|---|---|
| | Pressure | | psia | | | | | |
| PA1 | Test Cell | | 0 to 0.5 | x | | x | | |
| PA2 | Test Cell | | 0 to 1.0 | x | x | | | |
| PA3 | Test Cell | | 0 to 5.0 | x | | | x | |
| PC-1P | Thrust Chamber | CG1 | 0 to 1000 | x | | | x | |
| PC-3 | Thrust Chamber | CG1A | 0 to 1000 | x | x | x | | |
| PCASI-2 | Augmented Spark Igniter Chamber | IG1 | 0 to 1000 | x | | | | |
| PCGG-1P | Gas Generator Chamber | | 0 to 1000 | x | x | x | | |
| PCGG-2 | Gas Generator Chamber | GG1A | 0 to 1000 | x | | | | |
| PFASIJ | Augmented Spark Igniter Fuel Injection | | 0 to 1000 | x | | | | |
| PFJ-1A | Main Fuel Injection | CF2 | 0 to 1000 | x | | x | | |
| PFJ-2 | Main Fuel Injection | CF2A | 0 to 1000 | x | x | | | |
| PFJGG-1A | Gas Generator Fuel Injection | GF4 | 0 to 1000 | x | | | | |
| PFJGG-2 | Gas Generator Fuel Injection | GF4 | 0 to 1000 | x | | x | | |
| PFMI | Fuel Jacket Inlet Manifold | CF1 | 0 to 2000 | x | | | | |
| PFOI-1A | Fuel Tapoff Orifice Outlet | HF2 | 0 to 1000 | x | | | | |
| PFPC-1A | Fuel Pump Balance Piston Cavity | PF5 | 0 to 1000 | x | | | | |
| PFPD-1P | Fuel Pump Discharge | PF3 | 0 to 1500 | x | | | | |
| PFPD-2 | Fuel Pump Discharge | PF2 | 0 to 1500 | x | x | x | | |
| PFPI-1 | Fuel Pump Inlet | | 0 to 100 | x | | | | x |
| PFPI-2 | Fuel Pump Inlet | | 0 to 200 | x | | | | x |
| PFPI-3 | Fuel Pump Inlet | | 0 to 200 | | x | x | | |
| PFPS-1P | Fuel Pump Interstage | PF6 | 0 to 200 | x | | | | |
| PFRPO | Fuel Recirculation Pump Outlet | | 0 to 60 | x | | | | |
| PFRPR | Fuel Recirculation Pump Return Line | | 0 to 50 | x | | | | |
| PFST-1P | Fuel Start Tank | TF1 | 0 to 1500 | x | | x | | |
| PFST-2 | Fuel Start Tank | TF1 | 0 to 1500 | x | | | | x |
| PFUT | Fuel Tank Ullage | | 0 to 100 | x | | | | |
| PFVI | Fuel Tank Repressurization Nozzle Inlet | | 0 to 1000 | x | | | | |
| PFVL | Fuel Tank Repressurization Vent Line | | 0 to 1000 | x | | | | |
| PGBNI | Bypass Nozzle Inlet | TG8 | 0 to 200 | x | | | | |
| PHECMO | Pneumatic Control Module Outlet | | 0 to 750 | x | | | | |
| PHEOP | Oxidizer Recirculation Pump Helium Purge | | 0 to 150 | x | | | | |
| PHES | Helium Supply | | 0 to 5000 | x | | | | |
| PHET-1P | Helium Tank | NN1 | 0 to 3500 | x | | x | | |
| PHET-2 | Helium Tank | NN1 | 0 to 3500 | x | | | | x |
| PHRO-1A | Helium Regulator Outlet | NN2 | 0 to 750 | x | x | | | |
| POBSC | Oxidizer Bootstrap Conditioning | | 0 to 50 | x | | | | |
| POBV | Gas Generator Oxidizer Bleed Valve | GO2 | 0 to 2000 | x | | | | |
| POJ-1A | Main Oxidizer Injection | CO3 | 0 to 1000 | x | | | | |
| POJ-2 | Main Oxidizer Injection | CO3A | 0 to 1000 | x | | x | | |
| POJGG-1A | Gas Generator Oxidizer Injection | GO5 | 0 to 1000 | x | | x | | |

## TABLE III-1 (Continued)

| AEDC Code | Parameter | Tap No. | Range | Micro-SADIC | Magnetic Tape | Oscillograph | Strip Chart | X-Y Plotter |
|---|---|---|---|---|---|---|---|---|
| | Pressure | | | | | | | |
| POJGG-2 | Gas Generator Oxidizer Injection | GO5 | 0 to 1000 | x | | | | |
| POPBC-1A | Oxidizer Pump Bearing Coolant | PO7 | 0 to 500 | x | | | | |
| POPD-1P | Oxidizer Pump Discharge | PO3 | 0 to 1500 | x | | | | |
| POPD-2 | Oxidizer Pump Discharge | PO2 | 0 to 1500 | x | x | x | | |
| POPI-1 | Oxidizer Pump Inlet | | 0 to 100 | x | | | | x |
| POPI-2 | Oxidizer Pump Inlet | | 0 to 200 | x | | | | x |
| POPI-3 | Oxidizer Pump Inlet | | 0 to 100 | | | x | | |
| POPSC-1A | Oxidizer Pump Primary Seal Cavity | PO6 | 0 to 50 | x | | | | |
| PORPO | Oxidizer Recirculation Pump Outlet | | 0 to 115 | x | | | | |
| PORPR | Oxidizer Recirculation Pump Return | | 0 to 100 | x | | | | |
| POTI-1A | Oxidizer Turbine Inlet | TG3 | 0 to 200 | x | | | | |
| POTO-1A | Oxidizer Turbine Outlet | TG4 | 0 to 100 | x | | | | |
| POUT | Oxidizer Tank Ullage | | 0 to 100 | x | | | | |
| POVCC | Main Oxidizer Valve Closing Control | | 0 to 500 | x | x | | | |
| POVI | Oxidizer Tank Repressurization Line Nozzle Inlet | | 0 to 1000 | x | | | | |
| POVL | Oxidizer Tank Repressurization Line Nozzle Throat | | 0 to 1000 | x | | | | |
| PPUVI-1A | Propellant Utilization Valve Inlet | PO8 | 0 to 1000 | x | | | | |
| PPUVO-1A | Propellant Utilization Valve Outlet | PO9 | 0 to 500 | x | | | | |
| PTCFJP | Thrust Chamber Fuel Jacket Purge | | 0 to 100 | x | | | | |
| PTPP | Turbopump and Gas Generator Purge | | 0 to 250 | x | | | | |
| | Speeds | | rpm | | | | | |
| NFP-1P | Fuel Pump | PFV | 0 to 30, 000 | x | x | x | | |
| NFRP | Fuel Recirculation Pump | | 0 to 15, 000 | x | | | | |
| NOP-1P | Oxidizer Pump | POV | 0 to 12, 000 | x | x | x | | |
| NORP | Oxidizer Recirculation Pump | | 0 to 15, 000 | x | | | | |
| | Temperatures | | °F | | | | | |
| TA1 | Test Cell (North) | | -50 to +800 | x | | | | |
| TA2 | Test Cell (East) | | -50 to +800 | x | | | | |
| TA3 | Test Cell (South) | | -50 to +800 | x | | | | |
| TA4 | Test Cell (West) | | -50 to +800 | x | | | | |
| TAIP-1A | Auxiliary Instrument Package | | -300 to +200 | x | | | | |
| TBHR-1 | Helium Regulator Body (North Side) | | -100 to +50 | x | | | | |
| TBHR-2 | Helium Regulator Body (South Side) | | -100 to +50 | x | | | x | |
| TBSC | Oxidizer Bootstrap Conditioning | | -350 to +150 | x | | | | |
| TCLC | Main Oxidizer Valve Closing Control Line Conditioning | | -325 to +200 | x | | | | |

## TABLE III-1 (Continued)

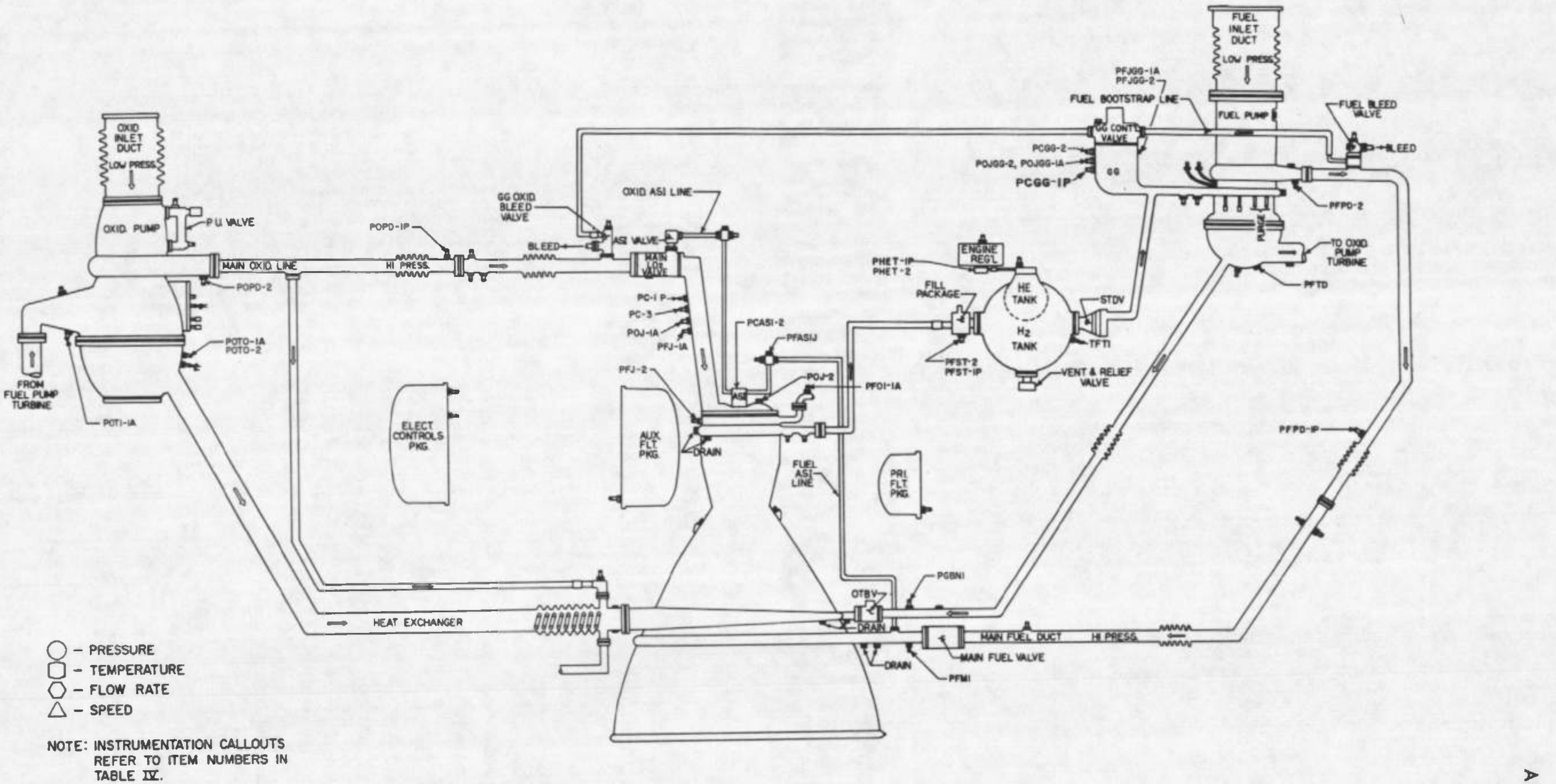
| AEDC Code | Parameter | Tap No. | Range | Micro-SADIC | Magnetic Tape | Oscillograph | Strip Chart | X-Y Plotter |
|---|---|---|---|---|---|---|---|---|
| | Temperatures | | °F | | | | | |
| TECP-1P | Electrical Control Package | NST1A | -300 to +200 | x | | | x | |
| TFASIJ | Augmented Spark Igniter Fuel Injection | 1FT1 | -425 to +100 | x | | x | | |
| TFASIL-1 | Augmented Spark Igniter Line | | -300 to +200 | x | | | x | |
| TFASIL-2 | Augmented Spark Igniter Line | | -300 to +300 | x | | | x | |
| TFBV-1A | Fuel Bleed Valve | GFT1 | -425 to -375 | x | | | | |
| TFJ-1P | Main Fuel Injection | CFT2 | -425 to +250 | x | x | x | | |
| TFPB-1A | Fuel Pump Bearing | | -425 to 325 | x | | | | |
| TFPD-1P | Fuel Pump Discharge | PFT1 | -425 to -400 | x | x | x | | |
| TFPD-2 | Fuel Pump Discharge | PFT1 | -425 to -400 | x | | | | |
| TFPDD | Fuel Pump Discharge Duct | | -320 to +300 | x | | | | |
| TFPI-1 | Fuel Pump Inlet | | -425 to -400 | x | | | | x |
| TFPI-2 | Fuel Pump Inlet | | -425 to -400 | x | | | | x |
| TFRPO | Fuel Recirculation Pump Outlet | | -425 to -410 | x | | | | |
| TFRPR | Fuel Recirculation Pump Return Line | | -425 to -250 | x | | | | |
| TFRT-1 | Fuel Tank | | -425 to -410 | x | | | | |
| TFRT-2 | Fuel Tank | | -425 to -410 | x | | | | |
| TFST-1P | Fuel Start Tank | TFT1 | -350 to +100 | x | | | | |
| TFST-2 | Fuel Start Tank | TFT1 | -350 to +100 | x | | | | x |
| TFTD-1 | Fuel Turbine Discharge Duct | | -200 to +800 | x | | | | |
| TFTD-1R | Fuel Turbine Discharge Collector | | -200 to +900 | x | | | | |
| TFTD-2 | Fuel Turbine Discharge Duct | | -200 to +1000 | x | | | x | |
| TFTD-3 | Fuel Turbine Discharge Duct | | -200 to +1000 | x | | | x | |
| TFTD-3R | Fuel Turbine Discharge Line | | -200 to +900 | x | | | | |
| TFTD-4 | Fuel Turbine Discharge Duct | | -200 to +1000 | x | | | | |
| TFTD-4R | Fuel Turbine Discharge Line | | -200 to +900 | x | | | | |
| TFTD-5 | Fuel Turbine Discharge Duct | | -200 to +1400 | x | | | | |
| TFTD-6 | Fuel Turbine Discharge Duct | | -200 to +1400 | x | | | | |
| TFTD-7 | Fuel Turbine Discharge Duct | | -200 to +1400 | x | | | | |
| TFTD-8 | Fuel Turbine Discharge Duct | | -200 to +1400 | x | | | x | |
| TFTI-1P | Fuel Turbine Inlet | TFT1 | 0 to 1800 | x | | | x | |
| TFTO | Fuel Turbine Outlet | TFT2 | 0 to 1800 | x | | | | |
| TGGO-1A | Gas Generator Outlet | GGT1 | 0 to 2000 | x | x | x | | |
| THET-1P | Helium Tank | NNT1 | -350 to +100 | x | | | | x |
| TMOVC | Main Oxidizer Valve Actuator Conditioning | | -325 to +200 | x | | | | |
| TOBS-1 | Oxidizer Bootstrap Line | | -300 to +250 | x | | | | |
| TOBS-2 | Oxidizer Bootstrap Line | | -300 to +250 | x | | | | |
| TOBS-2A | Oxidizer Bootstrap Line | | -300 to +250 | x | | | | |
| TOBS-2B | Oxidizer Bootstrap Line | | -300 to +250 | x | | | | |
| TOBS-3 | Oxidizer Bootstrap Line | | -300 to +250 | x | | | | |
| TOBS-4 | Oxidizer Bootstrap Line | | -300 to +250 | x | | | | |
| TOBSCI | Oxidizer Bootstrap Conditioning Inlet | | 0 to 100 | x | | | | |
| TOBSCO | Oxidizer Bootstrap Conditioning Outlet | | 0 to 100 | x | | | | |
| TOBV-1A | Oxidizer Bleed Valve | GOT2 | -300 to -250 | x | | | | |

## TABLE III-1 (Continued)

| AEDC Code | Parameter | Tsp No. | Range | Micro-SADIC | Magnetic Tape | Oscillo-graph | Strip Chart | X-Y Plotter |
|---|---|---|---|---|---|---|---|---|
| | Temperatures | | °F | | | | | |
| TOPB-1A | Oxidizer Pump Bearing Coolant | POT4 | -300 to -250 | x | | | | |
| TOPD-1P | Oxidizer Pump Discharge | POT3 | -300 to -250 | x | x | x | x | |
| TOPD-2 | Oxidizer Pump Discharge | POT3 | -300 to -260 | x | | | | |
| TOPDS | Oxidizer Pump Discharge Skin | | -300 to -100 | x | | | | |
| TOPI-1 | Oxidizer Pump Inlet | | -310 to -270 | x | | | | x |
| TOPI-2 | Oxidizer Pump Inlet | | -310 to -270 | x | | | | x |
| TORPO | Oxidizer Recirculation Pump Outlet | | -300 to -250 | x | | | | |
| TORPR | Oxidizer Recirculation Pump Return Line | | -300 to -140 | x | | | | |
| TORT-1 | Oxidizer Tank | | -300 to -287 | x | | | | |
| TORT-3 | Oxidizer Tank | | -300 to -287 | x | | | | |
| TOTI-1P | Oxidizer Turbine Inlet | TGT3 | 0 to 1200 | x | | | x | |
| TOTO-1P | Oxidizer Turbine Outlet | TGT4 | 0 to 1000 | x | | | | |
| TOVL | Oxidizer Tank Repressurization Line Nozzle Throat | | -300 to +100 | x | | | | |
| TPCC | Prechill Controller | | -425 to -300 | x | | | | |
| TPIP-1P | Primary Instrument Package | | -300 to +200 | x | | | | |
| TPPC | Pneumatic Package Conditioning | | -325 to +200 | x | | | | |
| TSC2-1 | Thrust Chamber Skin | | -300 to +500 | x | | | | |
| TSC2-2 | Thrust Chamber Skin | | -300 to +500 | x | | | | |
| TSC2-3 | Thrust Chamber Skin | | -300 to +500 | x | | | | |
| TSC2-4 | Thrust Chamber Skin | | -300 to +500 | x | | | | |
| TSC2-5 | Thrust Chamber Skin | | -300 to +500 | x | | | | |
| TSC2-6 | Thrust Chamber Skin | | -300 to +500 | x | | | | |
| TSC2-7 | Thrust Chamber Skin | | -300 to +500 | x | | | | |
| TSC2-8 | Thrust Chamber Skin | | -300 to +500 | x | | | | |
| TSC2-9 | Thrust Chamber Skin | | -300 to +500 | x | | | | |
| TSC2-10 | Thrust Chamber Skin | | -300 to +500 | x | | | | |
| TSC2-11 | Thrust Chamber Skin | | -300 to +500 | x | | | | |
| TSC2-12 | Thrust Chamber Skin | | -300 to +500 | x | | | | |
| TSC2-13 | Thrust Chamber Skin | | -300 to +500 | x | | | x | |
| TSC2-14 | Thrust Chamber Skin | | -300 to +500 | x | | | | |
| TSC2-15 | Thrust Chamber Skin | | -300 to +500 | x | | | | |
| TSC2-16 | Thrust Chamber Skin | | -300 to +500 | x | | | | |
| TSC2-17 | Thrust Chamber Skin | | -300 to +500 | x | | | | |
| TSC2-18 | Thrust Chamber Skin | | -300 to +500 | x | | | | |
| TSC2-19 | Thrust Chamber Skin | | -300 to +500 | x | | | x | |
| TSC2-20 | Thrust Chamber Skin | | -300 to +500 | x | | | | |
| TSC2-21 | Thrust Chamber Skin | | -300 to +500 | x | | | | |
| TSC2-22 | Thrust Chamber Skin | | -300 to +500 | x | | | | |
| TSC2-23 | Thrust Chamber Skin | | -300 to +500 | x | | | | |
| TSC2-24 | Thrust Chamber Skin | | -300 to +500 | x | | | | |
| TSOB | Skin Oxidizer Bootstrap Shroud | | -200 to +100 | x | | | | |
| TSOVAL-1 | Oxidizer Valve Closing Control Line | | -200 to +100 | x | | | | |

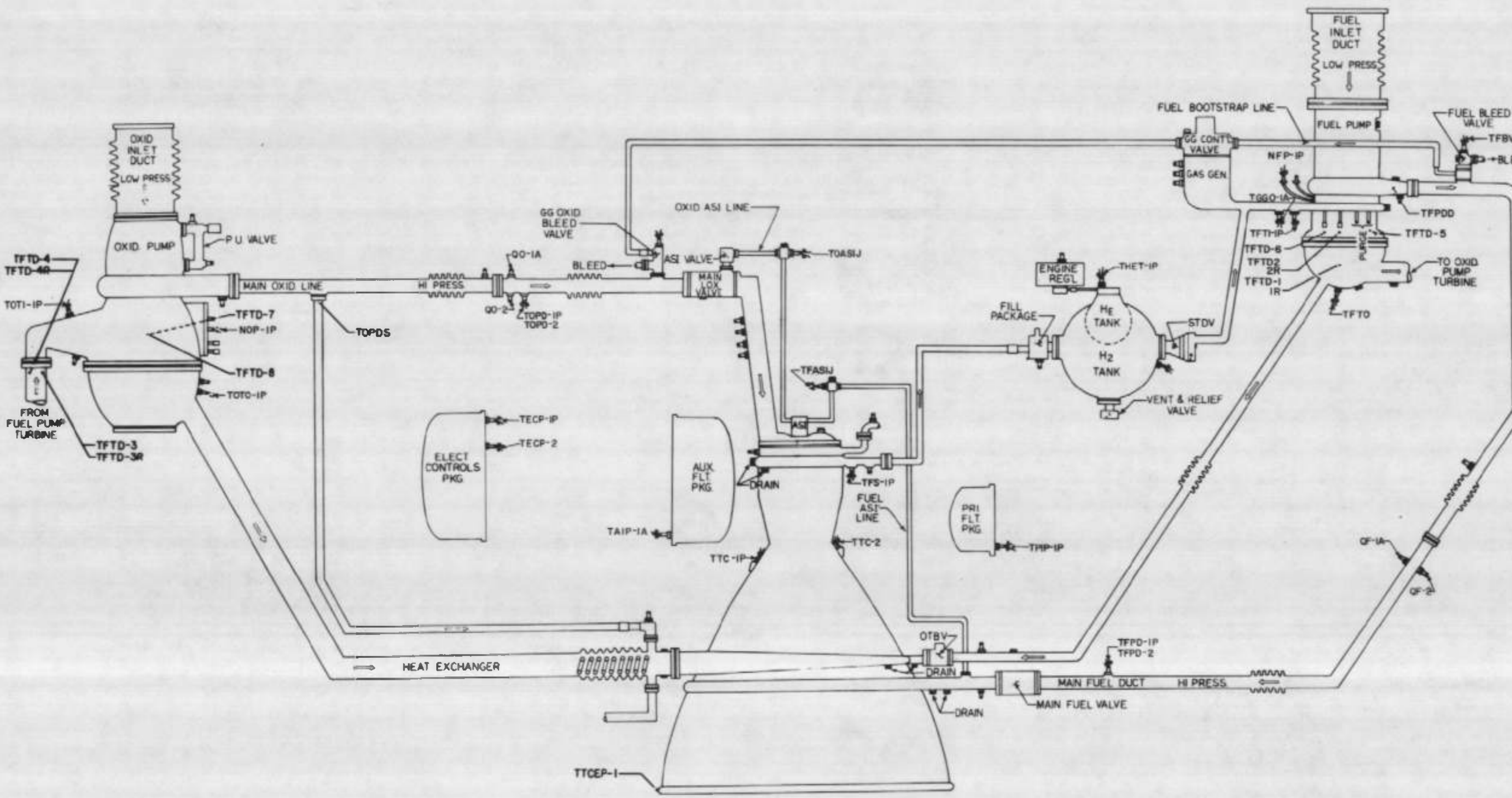
## TABLE III-1 (Concluded)

| AEDC Code | Parameter | Tap No. | Range | Micro-SADIC | Magnetic Tape | Oscillo-graph | Strip Chart | X-Y Plotter |
|---|---|---|---|---|---|---|---|---|
| | Temperatures | | °F | | | | | |
| TSOVAL-2 | Oxidizer Valve Closing Control Line | | -200 to +100 | x | | | x | |
| TSOVC-1 | Oxidizer Valve Actuator Cap | | -325 to +150 | x | | | | |
| TSOVC-2 | Oxidizer Valve Actuator Filter Flange | | -325 to +150 | x | | | | |
| TSTC | Start Tank Conditioning Upstream (PCV-N2-He) | | -350 to +150 | x | | | | |
| TSTDVOC | Start Tank Discharge Valve Opening Control Port | | -350 to +100 | x | | | | |
| TTC-1P | Thrust Chamber Jacket (Control) | CS1 | -425 to +500 | x | | | x | |
| TSGGOC | Gas Generator Opening Control Port | | -350 to +100 | x | | | | |
| TTCEP-1 | Thrust Chamber Exit | | -425 to +500 | x | | | | |
| TXOC | Crossover Duct Conditioning | | -325 to +200 | x | | | | |
| | Vibrations | | g | | | | | |
| UFPR | Fuel Pump (Radial 90°) | | ±200 | | x | | | |
| UOPR | Oxidizer Pump (Radial 90°) | | ±200 | | x | | | |
| UTCD-1 | Thrust Chamber Dome | | ±500 | | x | x | | |
| UTCD-2 | Thrust Chamber Dome | | ±500 | | x | x | | |
| UTCD-3 | Thrust Chamber Dome | | ±500 | | x | x | | |
| U1VSC | No. 1 Vibration Safety Counts | | On/Off | | | x | | |
| U2VSC | No. 2 Vibration Safety Counts | | On/Off | | | x | | |
| | Voltage | | Volts | | | | | |
| VCB | Control Bus | | 0 to 36 | x | | x | | |
| VIB | Ignition Bus | | 0 to 36 | x | | x | | |
| VIDA | Ignition Detect Amplifier | | 9 to 16 | x | | x | | |
| VPUTEP | Propellant Utilization Valve Excitstion | | 0 to 100 | x | | | | |
| RTCEP | Thrust Chamber Exhaust Plume | | 0 to 7 | x | | | x | |

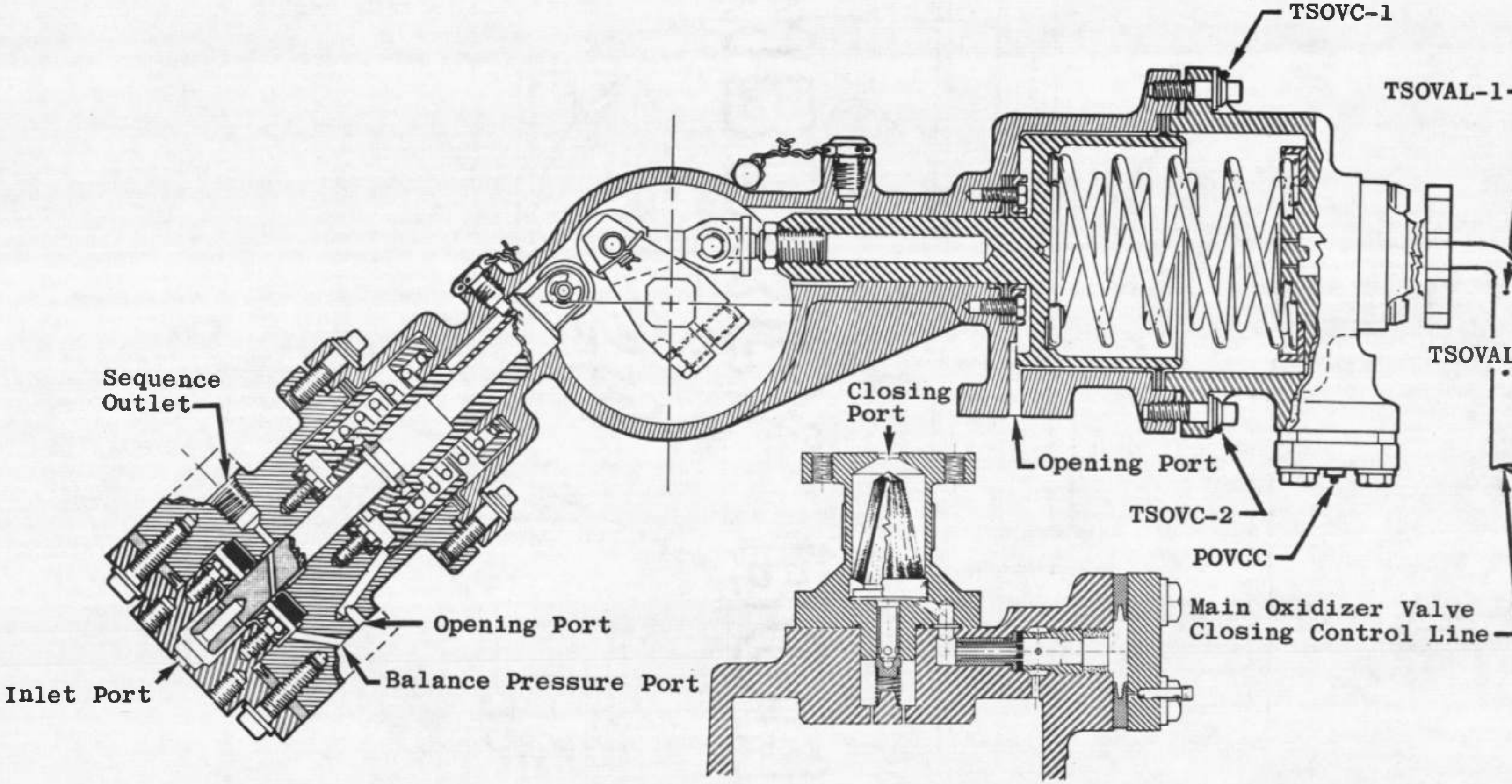



a. Engine Pressure Tap Locations

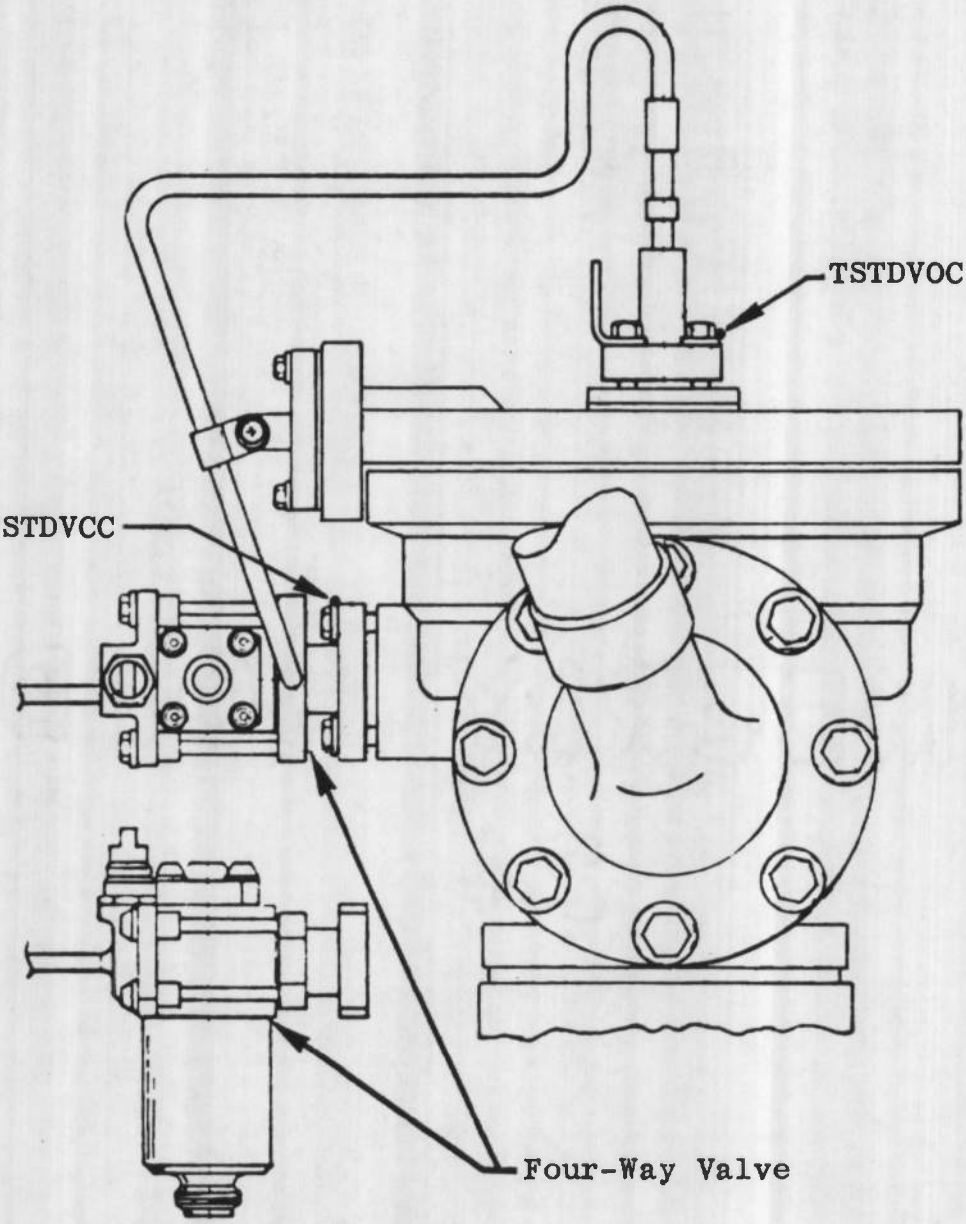
Fig. III-1 Instrumentation Locations



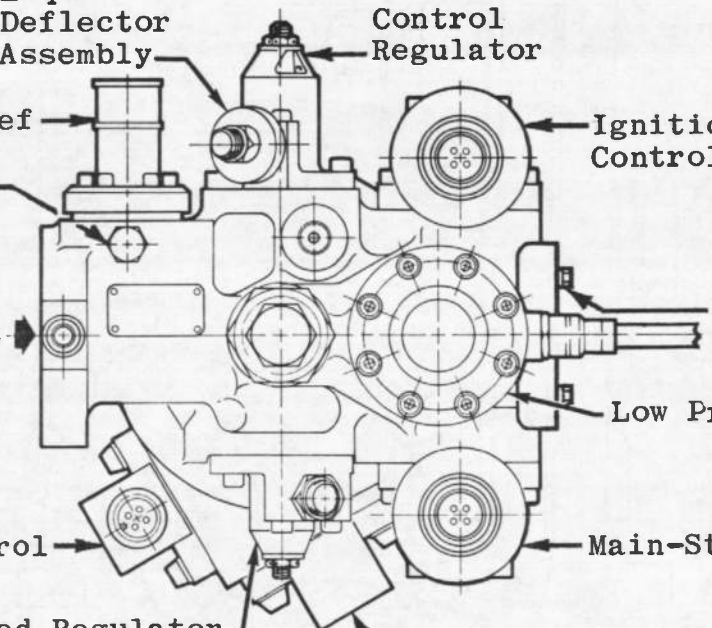

**b. Engine Temperature, Flow, and Speed Instrumentation Locations**
**Fig. III-1 Continued**




c. Main Oxidizer Valve
Fig. III-1 Continued

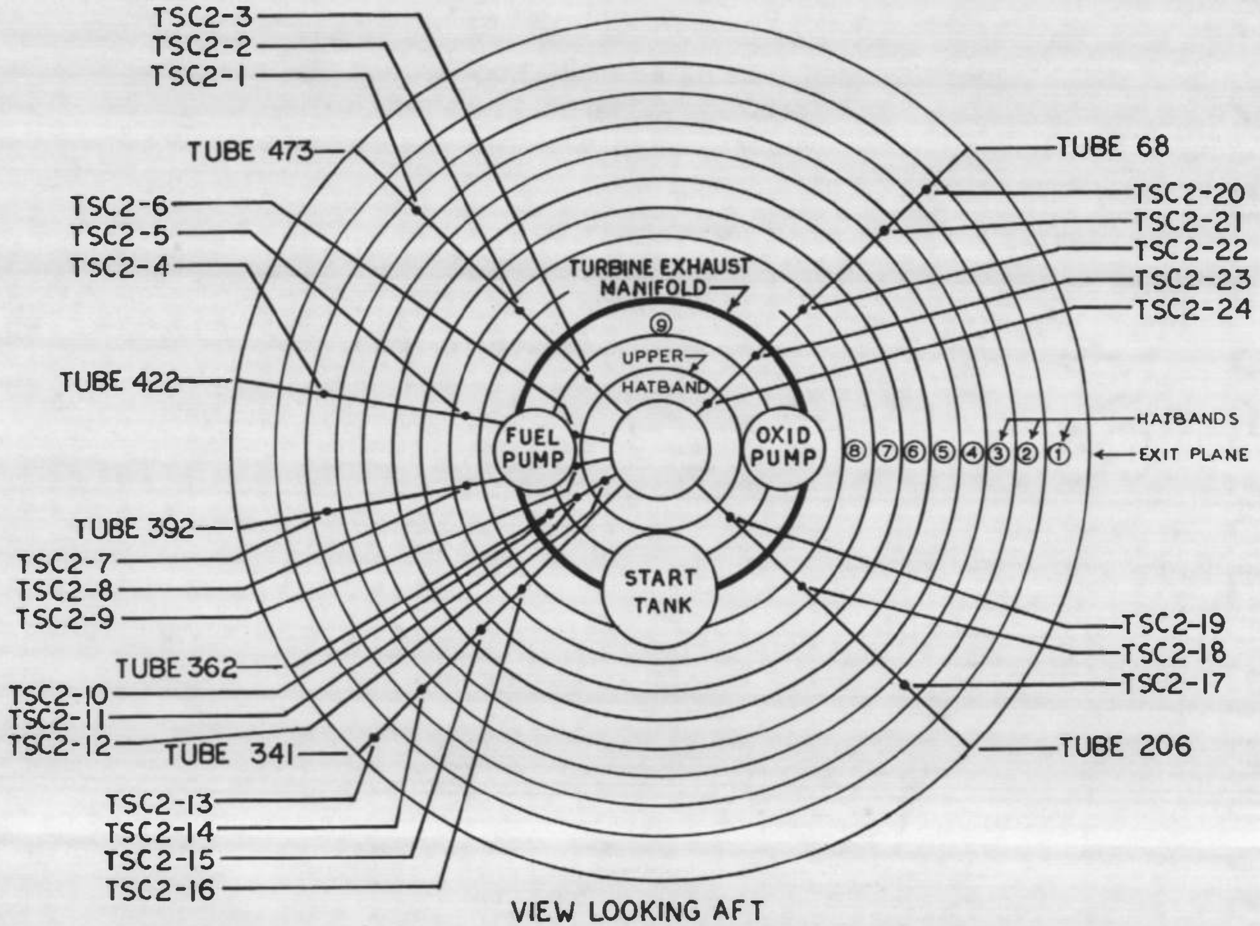



d. Start Tank Discharge Valve
Fig. III-1 Continued

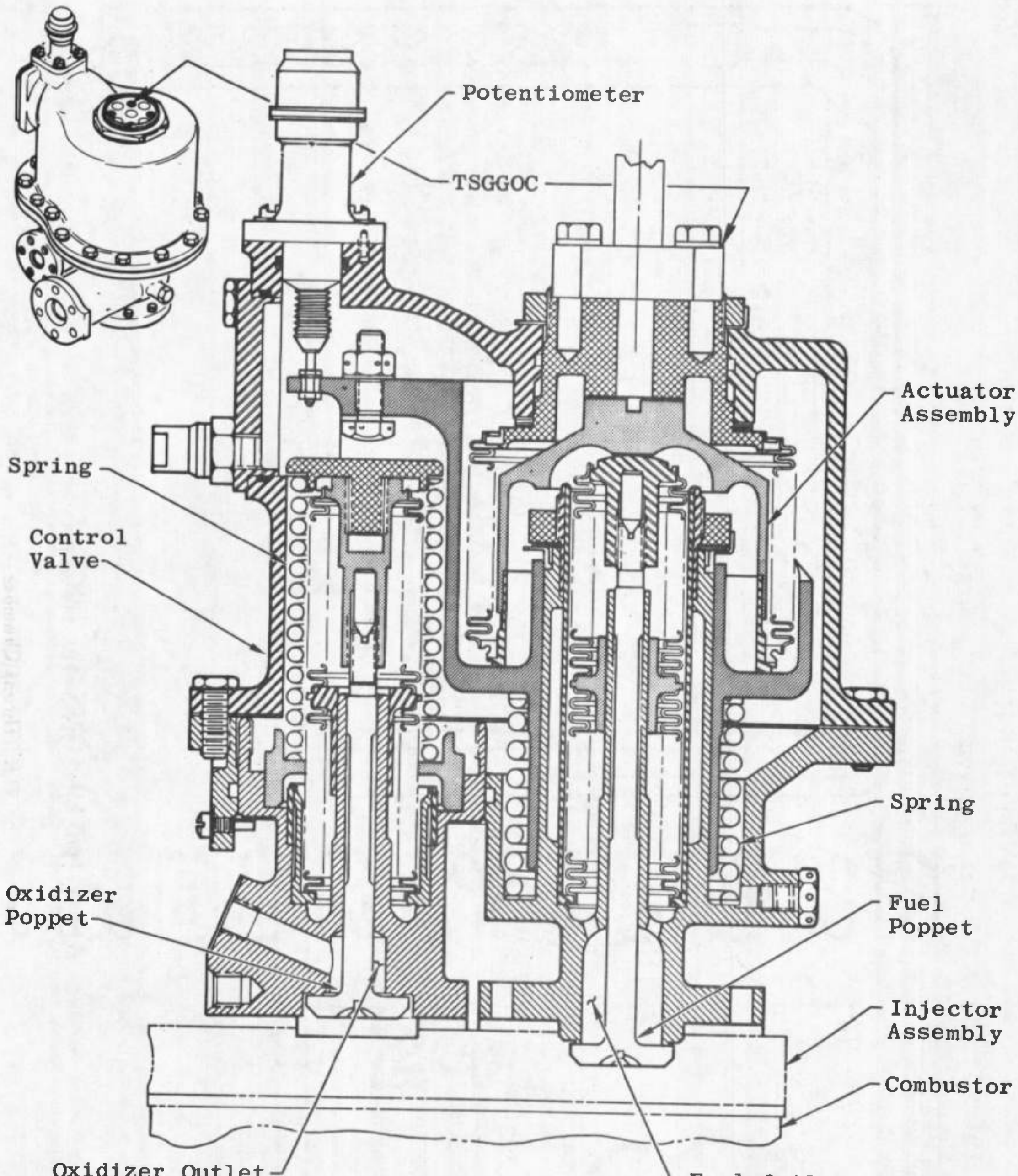



Top View

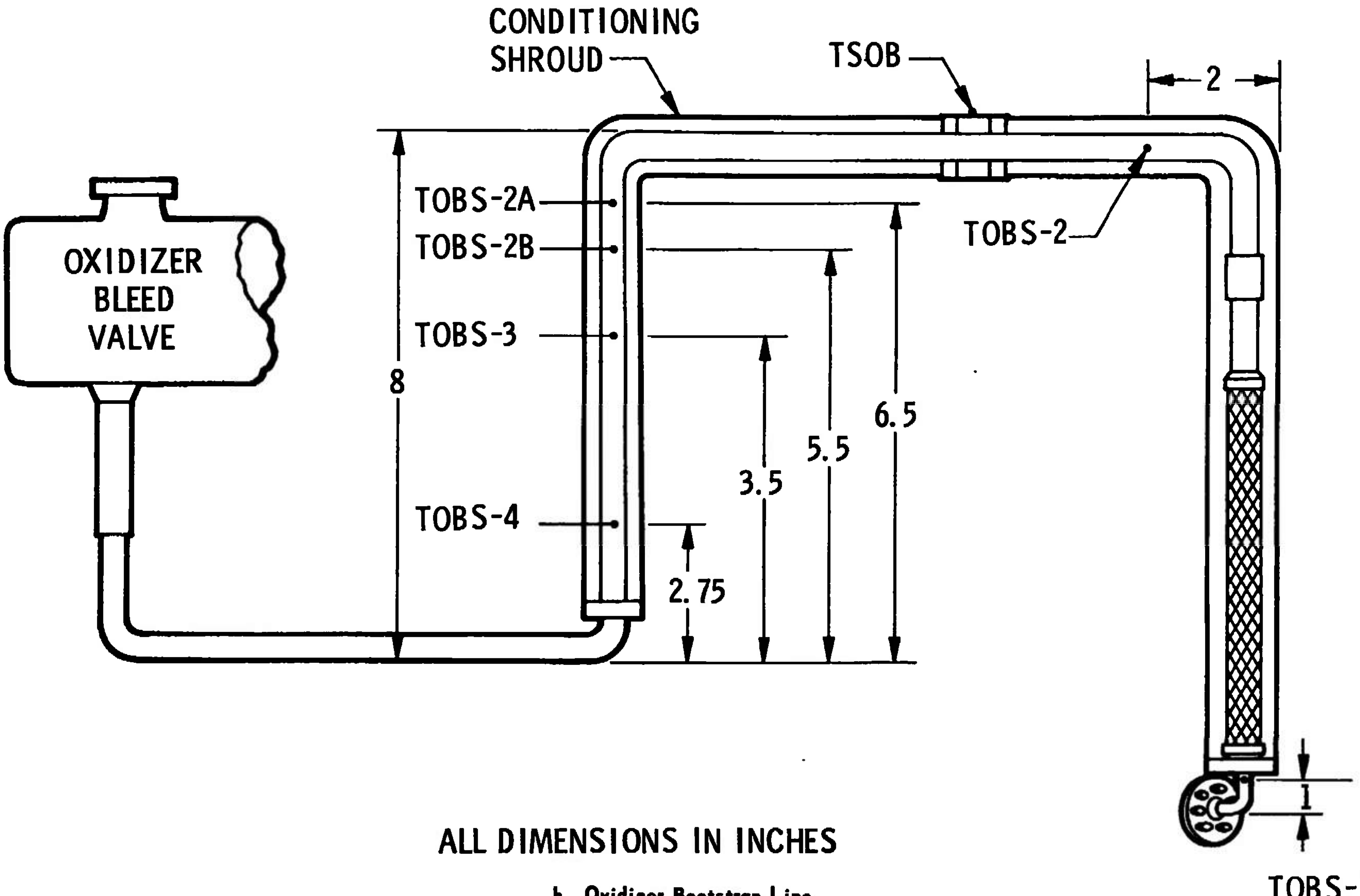
e. Helium Regulator
Fig. III-1 Continued



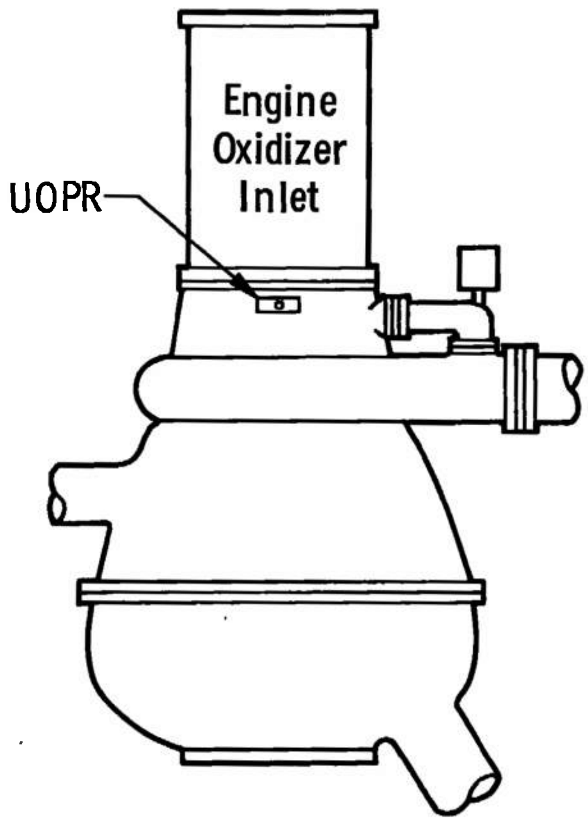

f. Thrust Chamber
Fig. III-1 Continued



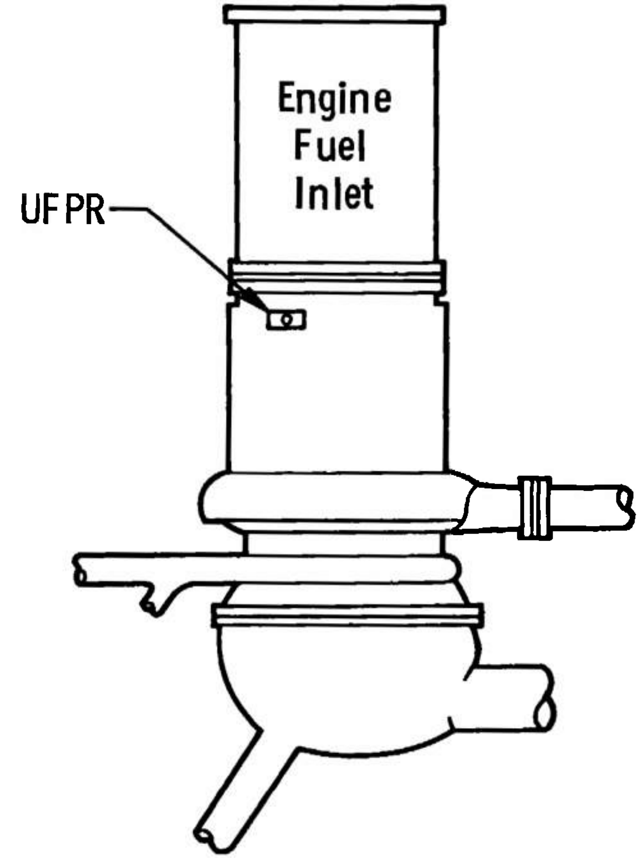

g. Gas Generator Control Valve
Fig. III-1 Continued




h. Oxidizer Bootstrap Line
Fig. III-1 Continued




View of Engine Looking North




i. Engine Inlets
Fig. III-1 Concluded

# APPENDIX IV
# METHODS OF CALCULATIONS
# (PERFORMANCE PROGRAM)

## TABLE IV-1

## TEST MEASUREMENTS REQUIRED BY PERFORMANCE PROGRAM

| Item No. | Parameter |
|---|---|
| 1 | Thrust Chamber (Injector Face) Pressure, psia |
| 2 | Thrust Chamber Fuel and Oxidizer Injection Pressures, psia |
| 3 | Thrust Chamber Fuel Injection Temperature, °F |
| 4 | Fuel and Oxidizer Flowmeter Speeds, Hz |
| 5 | Fuel and Oxidizer Engine Inlet Pressures, psia |
| 6 | Fuel and Oxidizer Pump Discharge Pressures, psia |
| 7 | Fuel and Oxidizer Engine Inlet Temperatures, °F |
| 8 | Fuel and Oxidizer (Main Valves) Temperatures, °F |
| 9 | Propellant Utilization Valve Center Tap Voltage, volts |
| 10 | Propellant Utilization Valve Position, volts |
| 11 | Fuel and Oxidizer Pump Speeds, rpm |
| 12 | Gas Generator Chamber Pressure, psia |
| 13 | Gas Generator (Bootstrap Line at Bleed Valve) Temperature, °F |
| 14 | Fuel* and Oxidizer Turbine Inlet Pressure, psia |
| 15 | Oxidizer Turbine Discharge Pressure, psia |
| 16 | Fuel and Oxidizer Turbine Inlet Temperature, °F |
| 17 | Oxidizer Turbine Discharge Temperature, °F |

*At AEDC, fuel turbine inlet pressure is calculated from gas generator chamber pressure.

## NOMENCLATURE

| | |
|---|---|
| A | Area, in.$^2$ |
| B | Horsepower, hp |
| C* | Characteristic velocity, ft/sec |
| $C_p$ | Specific heat at constant pressure, Btu/lb/°F |
| D | Diameter, in. |
| H | Head, ft |
| h | Enthalpy, Btu/$lb_m$ |
| M | Molecular weight |
| N | Speed, rpm |
| P | Pressure, psia |
| Q | Flow rate, gpm |
| R | Resistance, sec$^2$/ft$^3$-in.$^2$ |
| r | Mixture ratio |
| T | Temperature, °F |
| TC* | Theoretical characteristic velocity, ft/sec |
| W | Weight flow, lb/sec |
| Z | Pressure drop, psi |
| $\beta$ | Ratio |
| $\gamma$ | Ratio of specific heats |
| $\eta$ | Efficiency |
| $\theta$ | Degrees |
| $\rho$ | Density, lb/ft$^3$ |

### SUBSCRIPTS

| | |
|---|---|
| A | Ambient |
| AA | Ambient at thrust chamber exit |
| B | Bypass nozzle |

| | |
|---|---|
| BIR | Bypass nozzle inlet (Rankine) |
| BNI | Bypass nozzle inlet (total) |
| C | Thrust chamber |
| CF | Thrust chamber, fuel |
| CO | Thrust chamber, oxidizer |
| CV | Thrust chamber, vacuum |
| E | Engine |
| EF | Engine fuel |
| EM | Engine measured |
| EO | Engine oxidizer |
| EV | Engine, vacuum |
| e | Exit |
| em | Exit measured |
| F | Thrust |
| FIT | Fuel turbine inlet |
| FM | Fuel measured |
| FY | Thrust, vacuum |
| f | Fuel |
| G | Gas generator |
| GF | Gas generator fuel |
| GO | Gas generator oxidizer |
| H1 | Hot gas duct No. 1 |
| H1R | Hot gas duct No. 1 (Rankine) |
| H2R | Hot gas duct No. 2 (Rankine) |
| IF | Inlet fuel |
| IO | Inlet oxidizer |
| ITF | Isentropic turbine fuel |
| ITO | Isentropic turbine oxidizer |
| N | Nozzle |
| NB | Bypass nozzle (throat) |

| | |
|---|---|
| NV | Nozzle, vacuum |
| O | Oxidizer |
| OC | Oxidizer pump calculated |
| OF | Outlet fuel pump |
| OFIS | Outlet fuel pump isentropic |
| OM | Oxidizer measured |
| OO | Oxidizer outlet |
| PF | Pump fuel |
| PO | Pump oxidizer |
| PUVO | Propellant utilization valve oxidizer |
| RNC | Ratio bypass nozzle, critical |
| SC | Specific, thrust chamber |
| SCV | Specific thrust chamber, vacuum |
| SE | Specific, engine |
| SEV | Specific, engine vacuum |
| T | Total |
| $T_O$ | Turbine oxidizer |
| TEF | Turbine exit fuel |
| TEFS | Turbine exit fuel (static) |
| TF | Fuel turbine |
| TIF | Turbine inlet fuel (total) |
| TIFM | Turbine inlet, fuel, measured |
| TIFS | Turbine inlet fuel isentropic |
| TIO | Turbine inlet oxidizer |
| t | Throat |
| V | Vacuum |
| v | Valve |
| XF | Fuel tank repressurant |
| XO | Oxidizer tank repressurant |

# PERFORMANCE PROGRAM EQUATIONS

## MIXTURE RATIO

### Engine

$$r_E = \frac{W_{EO}}{W_{EF}}$$

$$W_{EO} = W_{OM} - W_{XO}$$

$$W_{EF} = W_{FM} - W_{XF}$$

$$W_E = W_{EO} + W_{EF}$$

### Thrust Chamber

$$r_C = \frac{W_{CO}}{W_{CF}}$$

$$W_{CO} = W_{OM} - W_{XO} - W_{GO}$$

$$W_{CF} = W_{FM} - W_{XF} - W_{GF}$$

$$W_{XO} = 0.8 \text{ lb/sec}$$

$$W_{XF} = 1.8 \text{ lb/sec}$$

$$W_{GO} = W_T - W_{GF}$$

$$W_{GF} = \frac{W_T}{1 + r_G}$$

$$W_T = \frac{P_{TIF}\, A_{TIF}\, K_7}{TC^*_{TIF}}$$

$$K_7 = 32.174$$

$$W_C = W_{CO} + W_{CF}$$

## CHARACTERISTIC VELOCITY

### Thrust Chamber

$$C^* = \frac{K_7\, P_c\, A_t}{W_C}$$

$$K_7 = 32.174$$

## DEVELOPED PUMP HEAD

Flows are normalized by using the following inlet pressures, temperatures, and densities.

$$P_{IO} = 39 \text{ psia}$$

$$P_{IF} = 30 \text{ psia}$$

$$\rho_{IO} = 70.79 \text{ lb/ft}^3$$

$$\rho_{IF} = 4.40 \text{ lb/ft}^3$$

$$T_{IO} = -295.212\,^\circ F$$

$$T_{IF} = -422.547\,^\circ F$$

Oxidizer

$$H_O = K_4 \left(\frac{P_{OO}}{\rho_{OO}} - \frac{P_{IO}}{\rho_{IO}}\right)$$

$$K_4 = 144$$

$$\rho = \text{National Bureau of Standards Values f (P,T)}$$

Fuel

$$H_f = 778.16\,\Delta h_{OFIS}$$

$$\Delta h_{OFIS} = h_{OFIS} - h_{IF}$$

$$h_{OFIS} = f(P,T)$$

$$h_{IF} = f(P,T)$$

## PUMP EFFICIENCIES

Fuel, Isentropic

$$\eta_f = \frac{h_{OFIS} - h_{IF}}{h_{OF} - h_{IF}}$$

$$h_{OF} = f(P_{OF}, T_{OF})$$

Oxidizer, Isentropic

$$\eta_O = \eta_{OC}\, Y_O$$

$$\eta_{OC} = K_{40} \left(\frac{Q_{PO}}{N_O}\right)^2 - K_{50} \left(\frac{Q_{PO}}{N_O}\right) + K_{60}$$

$$K_{40} = 5.0526$$

$$K_{50} = 3.8611$$

$$K_{60} = 0.0733$$

$$Y_O = 1.000$$

**TURBINES**

Oxidizer, Efficiency

$$\eta_{TO} = \frac{B_{TO}}{B_{ITO}}$$

$$B_{TO} = K_5 \frac{W_{PO} \ H_O}{\eta_O}$$

$$K_5 = 0.001818$$

$$W_{PO} = W_{OM} + W_{PUVO}$$

$$W_{PUVO} = \sqrt{\frac{Z_{PUVO} \ \rho_{OO}}{R_v}}$$

$$Z_{PUVO} = A + B \ (P_{OO})$$

$$A = -1597$$

$$B = 2.3828$$

IF $P_{OO} \geq 1010$ Set $P_{OO} = 1010$

$$\ln R = A_3 + B_3 (\theta_{PUVO}) + C (\theta_{PUVO})^3 + D_3 (e)^{\frac{\theta_{PUVO}}{7}} + E_3 (\theta_{PUVO}) (e)^{\frac{\theta_{PUVO}}{7}} + F_3 \left[ (e)^{\frac{\theta_{PUVO}}{7}} \right]^2$$

$$A_3 = 5.5659 \times 10^{-1}$$

$$B_3 = 1.4997 \times 10^{-2}$$

$$C_3 = 7.9413 \times 10^{-6}$$

$$D_3 = 1.2343$$

$$E_3 = -7.2554 \times 10^{-2}$$

$$F_3 = 5.0691 \times 10^{-2}$$

$$\theta_{PUVO} = 16.5239$$

Fuel, Efficiency

$$\eta_{TF} = \frac{B_{TF}}{B_{ITF}}$$

$$B_{ITF} = K_{10} \ \Delta h_f \ W_T$$

$$\Delta h_f = h_{TIF} - h_{TEF}$$

$$B_{TF} = B_{PF} = K_5 \left( \frac{W_{PF} \ H_f}{\eta_f} \right)$$

$$W_{PF} = W_{FM}$$

$$K_{10} = 1.4148$$

$$K_5 = 0.001818$$

Oxidizer, Developed Horsepower

$$B_{TO} = B_{PO} + K_{56}$$

$$B_{PO} = K_5 \frac{W_{PO} H_O}{\eta_O}$$

$$K_{56} = -15$$

Fuel, Developed Horsepower

$$B_{TF} = B_{PF}$$

$$B_{PF} = K_5 \frac{W_{PF} H_f}{\eta_f}$$

$$W_{PF} = W_{FM}$$

Fuel, Weight Flow

$$W_{TF} = W_T$$

Oxidizer Weight Flow

$$W_{TO} = W_T - W_B$$

$$W_B = \left[\frac{2K_7 \quad H_2}{\gamma_{H2-1}} (P_{RNC})^{\frac{2}{\gamma_{H2}}}\right]^{1/2} \left[1 - (P_{RNC})^{\frac{\gamma_{H2-1}}{\gamma_{H2}}}\right] \frac{A_{NB} \; P_{BNI}}{(R_{H2} T_{BIR})^{1/2}}$$

$$P_{RNC} = f\,(\beta_{NB}, \gamma_{H_2})$$

$$\beta_{NB} = \frac{D_{NB}}{D_B}$$

$$\gamma_{H2}, M_{H2} = f(T_{H2R}, R_G)$$

$$A_{NB} = K_{13}\, D_{NB}$$

$$K_{13} = 0.7854$$

$$T_{BIR} = T_{TIO} + 460$$

$$P_{BNI} = P_{TEFS}$$

$$P_{TEFS} = \text{Iteration of } P_{TEF}$$

$$P_{TEF} = P_{TEFS}\left[1 + K_8 \left(\frac{W_T}{P_{TEFS}}\right)^2 \frac{T_{H2R}}{D^4_{TEF}\, M_{H2}} \left(\frac{\gamma_{H2-1}}{\gamma_{H2}}\right)\right]^{\frac{\gamma_{H2}}{\gamma_{H2-1}}}$$

$$K_8 = 38.8983$$

**GAS GENERATOR**

Mixture Ratio

$$r_G = D_1 (T_{H1})^3 + C_1 (T_{H1})^2 + B_1 (T_{H1}) + A_1$$

$$A_1 = 0.2575$$

$$B_1 = 5.586 \times 10^{-4}$$

$$C_1 = -5.332 \times 10^{-9}$$

$$D_1 = 1.1312 \times 10^{-11}$$

$$T_{H1} = T_{TIFM}$$

Flows

$$TC^*_{TIF} = D_2 (T_{H1})^3 + C_2 (T_{H1})^2 + B_2 (T_{H1}) + A_2$$

$$A_2 = 4.4226 \times 10^3$$

$$B_2 = 3.2267$$

$$C_2 = -1.3790 \times 10^{-3}$$

$$D_2 = 2.6212 \times 10^{-7}$$

$$P_{TIF} = P_{TIFS} \left[ 1 + K_8 \left( \frac{W_T}{P_{TIFS}} \right)^2 \frac{T_{H1R}}{D^4{}_{TIF} M_{H1}} \cdot \frac{\gamma_{H1} - 1}{\gamma_{H1}} \right]^{\frac{\gamma_{H1}}{\gamma_{H1} - 1}}$$

$$K_8 = 38.8983$$

Note: $P_{TIF}$ is determined by iteration.

$$T_{HIR} = T_{TIF}$$

$$M_{H1}, \gamma_{H1}, C_p, r_{H1} = f\,(T_{HIR}, r_G)$$

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Security Classification

**DOCUMENT CONTROL DATA - R & D**

*(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)*

| | |
|---|---|
| 1. ORIGINATING ACTIVITY (Corporate author)<br>Arnold Engineering Development Center,<br>ARO, Inc., Operating Contractor,<br>Arnold Air Force Station, Tennessee | 2a. REPORT SECURITY CLASSIFICATION<br>UNCLASSIFIED<br>2b. GROUP<br>N/A |

3. REPORT TITLE

ALTITUDE DEVELOPMENTAL TESTING OF THE J-2 ROCKET ENGINE IN PROPULSION ENGINE TEST CELL (J-4) (TEST J4-1801-04)

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

August 3, 1967 - Interim Report

5. AUTHOR(S) (First name, middle initial, last name)

N. S. Dougherty, Jr., ARO, Inc.

| | | |
|---|---|---|
| 6. REPORT DATE<br>January 1968 | 7a. TOTAL NO. OF PAGES<br>111 | 7b. NO. OF REFS<br>8 |

| | |
|---|---|
| 8a. CONTRACT OR GRANT NO. AF40(600)-1200<br>b. PROJECT NO. 9194<br>c. System 921E<br>d. | 9a. ORIGINATOR'S REPORT NUMBER(S)<br>AEDC-TR-67-228<br>9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)<br>N/A |

10 DISTRIBUTION STATEMENT Subject to special export controls; transmittal to foreign governments or foreign nationals requires approval of NASA, Marshall Space Flight Center (I-E-J), Huntsville, Alabama. Transmittal outside of DOD requires approval of NASA, Marshall Space Flight Center*

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|---|---|
| 11 SUPPLEMENTARY NOTES<br>Available in DDC. | 12. SPONSORING MILITARY ACTIVITY<br>NASA, Marshall Space Flight Center (I-E-J), Huntsville, Alabama |

13. ABSTRACT


Four firings of the Rocketdyne J-2 rocket engine were conducted in Test Cell J-4 of the Large Rocket Facility. A fifth firing attempt was aborted at t - 1 sec because the gas generator oxidizer supply line contained liquid-phase oxidizer. The firings were accomplished during test period J4-1801-04 at pressure altitudes ranging from 100,000 to 109,500 ft at engine start at predicted maximum starting energy S-V/S-IVB first burn conditions and maximum and minimum energy orbital restarting conditions. Satisfactory engine operation was obtained. The accumulated firing duration was 95.3 sec.

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| 14. KEY WORDS | LINK A | | LINK B | | LINK C | |
|---|---|---|---|---|---|---|
| | ROLE | WT | ROLE | WT | ROLE | WT |
| J-2 rocket engines<br>altitude testing<br>performance<br>gas generator ignition characteristics<br>fuel pump stall margin | | | | | | |

1. Rocket motors -- J-2
2. " " -- Performance
3. " " -- Ignition
4. " " -- Fuel pump stall
5. " " -- Ignition

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